THE ROMANCE OF MODERN ENGINEERING

ARCHIBALD WILLIAMS

The Romance of
Modern Engineering

A

A notable feature of the structure is that the ironwork is quite independent of the masonry, which is out of contact with the real supports, concealed inside.

The foundations of the two towers are capable of supporting without settlement, a weight of 70,000 tons.

Photo by] [*Thiele.*

This Interesting View of the Tower Bridge shows the "Bascules" of the Central Span raised to permit the passage of Shipping.

[*Frontispiece.*

The Romance of Modern Engineering

Containing Interesting Descriptions in Non-Technical Language of the Nile Dam, the Panama Canal, the Tower Bridge, the Brooklyn Bridge, the Trans-Siberian Railway, the Niagara Falls Power Co., Bermuda Floating Dock etc. etc.

By

Archibald Williams

Author of "The Romance of Modern Invention"

With many Illustrations

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Preface

As it would be impossible to treat, in the compass of a few hundred pages, all the great engineering feats of modern times without reducing individual accounts to uninteresting brevity, the author has preferred, where selection is possible, to take typical instances of engineering practice, and, by the aid of comparatively detailed descriptions, to place the reader in a position to appreciate them and similar undertakings.

He desires here gratefully to acknowledge the help received from engineers and other gentlemen professionally connected with the great works that are the subjects of the following chapters, and to thank the proprietors of certain publications for permission to make use of the same.

1904.

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The Romance of Modern Engineering

CHAPTER I

THE HARNESSING OF NIAGARA

It is indeed hard to conceive that any one in full possession of his senses could stand unmoved in the presence of a great waterfall. The sight of huge masses of water, tumbling as it were from the blue of the very heavens, dissolving into arrowy streams as they descend before the final crash into the mist-laden gulf below, must appeal even to the most brutalised mind by its sheer majesty and magnificence.

What then are the thoughts of those whose emotions are strings easily attuned to the grander moods of Nature?

The first impression is doubtless one of awe, called forth by the involuntary comparison between our own insignificance and the immensity of the force before us. What right have we, frail creatures of a day, to speak of lordship of creation face to face with this watery avalanche that has thundered down for centuries, nay thousands of years? What can

human art avail against the violence of those ceaseless, seething torrents, stunning our ears with sound, dazzling our eyes to weariness by their motion?

Then follow what we may call the secondary emotions. The poet feels the inspiration of descriptive verse: the artist reaches for his pencil. The engineer, or man of science, not less alive, perhaps, to the artistic beauty of the scene, yet from habit and profession sees here a mighty source of Power, of motive force to drive the myriad whirring wheels conjured into being by civilisation and its needs.

"I look forward," said Lord Kelvin at Niagara Falls, "to the time when the whole water from Lake Erie will find its way to the lower level of Lake Ontario through machinery, doing more good for the world than that great benefit which we now possess in the contemplation of the splendid scene now presented by the waterfalls of Niagara." On another occasion another famous electrician, Sir William Siemens, looked upon the scene with similar thoughts. "The stupendous rush of waters filled him with fear and admiration, as it does every one who comes within the sound of its mighty roar. But he saw in it something far beyond what was obvious to the multitude, for his scientific mind could not help viewing it as an inexpressible manifestation of mechanical energy—and he at once began to speculate whether it was absolutely necessary that the whole of this glorious magnitude of power should be wasted in dashing itself into the chasm below—whether it was

not possible that at least some might be practically utilised for the benefit of mankind."[1]

It seems as if we may trace the finger of a perverse Fate in the necessity that drives us, in an age when man is peculiarly appreciative of the beauties of nature, to invade with our instruments and machines some of the fairest spots on earth. To obtain a good water supply we throw a huge mass of masonry across the Nile, and dam lovely valleys; to furnish us with timber stately forests are levelled; to yield us coal and iron smiling country-sides are disfigured by towering chimneys, and the atmosphere filled with a foul reek. And that our source of energy may be in proportion to our wants the rushing mountain stream in Norway, Switzerland, Italy, France, and elsewhere is hemmed in by walls and weirs, and its only way to freedom lies through huge pipes to whirling turbines. Much as we must regret these things, we know that they are inevitable. Many of the conditions of life are changing. To-day that nation is ascendant which is not necessarily hardiest, or numbers the bravest hearts and stoutest arms, but, as we are told, that one which can produce the cheapest ton of steel. In other words, wealth holds the balances: wealth depends on commerce; commerce comes to those who are able to hold their own against the world in the fierce struggle of economical production. To carry the train a little further, econo-

[1] From William Pole's "Life of Sir William Siemens."

mical production is based upon a plentiful supply of cheap energy, whether in the form of motive force or heat. The manufacturer is so eager to clip off a decimal of a cent here or a fraction of a penny there from the cost at which he can produce his goods, that any method for cheapening the prime mover—Power—of his factories is gladly welcomed. The engineer is always busy bringing the latest appliances of science to his aid. We hear of enormous steam-engines, many times more efficient than those of half a century ago; of great machines actuated by explosions of gas—formidable competitors to Giant Steam: and Water-Power in its newest developments is fast pushing its way to the front, threatening both steam and explosive vapour. Coal-fields are exhaustible, oil-fields are exhaustible, but a river "flows on for ever." Once in harness, water becomes man's servant for the ages.

As a consequence of the new lease of life given to water-power, we may expect to see great changes in the industrial world. Hitherto trade and manufacture have gone to those countries which possess well-worked coal-fields. In the future a bid for supremacy will be made by those districts where the force of gravitation, as represented by falling water, may be cheaply transformed into other forms of energy. Numerous experiments and statistics prove that the steam-engine has almost reached its limit of economy; we cannot expect to get much more power from every pound of coal we burn than we do now. The cost of

raising that pound from the bowels of the earth tends to increase as the supply decreases.

Many great water-power installations are already in full working: on the Rhone, the Rhine, the Adda, the Reuss, the Aar. Hundreds of thousands of horse-power are daily produced at the turbines, and flashed noiselessly to thousands of machines, through great cables pulsating with electricity.

But at Niagara, the electrical Mecca of the world, Nature has furnished mankind with the most magnificent of power-houses. Here the overflow from four lakes, or rather inland seas, linked so as to form one huge reservoir of 90,000 square miles, is herded by cliffs into a narrow channel and compelled to make a magnificent leap of 165 sheer feet into the lower river. The figures are almost appalling. A solid wall of water 20 feet deep, representing 275,000 cubic feet per second, passes over the Falls continuously. Its daily force, some seven million horse-power, equals that of the latent power of the 200,000 tons of coal mined every twenty-four hours throughout the world. Think of the thousands upon thousands of stately ships furrowing the ocean, the myriads of locomotives that flash over the iron ways, the huge boilers bringing movement to countless factories; their combined average energy is not equal to that running to waste at the "Roaring of the Waters."

Now, were Niagara situated in some desolate, sterile, Arctic region, the eyes of engineers would still turn longingly to its enormous power. Nature has,

however, dealt kindly with the human race in placing the Falls where they are : in a healthful country teeming with natural resources, among peoples of superabundant energy. It would be almost less a matter for surprise were the waters to leap upwards, than that the enterprising American and Canadian should fail to utilise the vast power flowing past his doors. Niagara Falls are the right thing in the right place. The time has come when toll can be taken of those rushing waters. Electricity, the Genius of the twentieth century, has long burst its swaddling bands, and can be united to water in a most advantageous partnership.

Ever since the first saw-mill was set up at Niagara in 1725, the idea of subjecting some part of the enormous power of the Falls to industrial uses has stirred the inventive faculty of engineers and manufacturers Early in the eighteenth century they cast about for a means of harnessing this lavish provision of nature, but the scientific knowledge of the world had not yet sufficiently advanced. In the nineteenth century steam and steam-power made such progress that manufacturers quitted the riverside for the coal-field. But the advantages of water were not forgotten. In 1842 we find Augustus Porter, one of the principal proprietors of Niagara, proposing a system of canals to the high bluffs overlooking the Falls, whence the water might fall over large wheels to drive the machinery of mills. As a result of continuous negotiations a syndicate of gentlemen obtained a right to

construct a canal 35 feet wide, 8 feet deep, and 4400 feet long, from the water of the Upper Niagara River to these bluffs, where, by 1885, the available capacity of the canal was being converted into some 10,000 horse-power.

Still greater projects were to follow. Mr. Thomas Evershed, an engineer who has done noble work in protecting the Falls from utilitarian desecration, was called upon the same year (1885) to develop a plan whereby the beauty of the Falls might be preserved, and at the same time a large bulk of water turned to practical purposes. He conceived the idea of tapping the Niagara above the Falls, precipitating the water into a huge pit, where machinery would be stationed, and carrying the waste away through a large tunnel, nearly 1½ miles long, to an outlet below the Falls. His plan was strongly opposed as impracticable, but in spite of discouragement eight gentlemen of Niagara obtained from the New York Legislature in 1886 a special charter, granting the right to take from the upper river sufficient water to develop 200,000 horse-power. A second concession, of a later date, from the Canadian Government, permits the same Company—now known as the Niagara Falls Power Company—to draw from the Canadian side an additional quarter million of horse-power. It has been estimated that the difference of level made at the edge of the Falls by the withdrawal of all this water will be but a few inches, not enough to detract in any way from the scenic effect of Niagara.

The Company also bought land extending for about $2\frac{1}{4}$ miles along the river, intending to lease or sell it for factories as soon as the plant was in working order, and to erect on it a residential quarter for the operatives.

On paper the Company's prospects were decidedly attractive. Their total horse-power represented more than a third of the total produced by water in the States in 1880. Niagara was within a night's journey of Boston, New York, and Philadelphia, Chicago, Pittsburg, Toronto, and Montreal. Within a radius of 400 miles dwelt one-fifth of the population of the States. It was the natural port of the great Lakes. It also lay in the neighbourhood of the great coal-fields. This last consideration raised the question—"Could Niagara power compete successfully with steam-made power?" After careful consideration the Company decided that it certainly could, and might even be carried at a profit into the coal-fields themselves.

As soon as great financiers had lent their names and support to the undertaking, the officers and directors of the Company proceeded to attack the problem of how best to convert the water they had permission to control into energy. The problem, says Mr. L. B. Stillwell, electrical engineer of the Company, was one "without precedent in its magnitude, and almost without parallel in its significance." The promoters of the scheme made up their minds to spare no expense or trouble to ensure the installation

of the best machinery in the best possible manner then known. They called in to their aid leading engineers and electricians of all countries, thus exhibiting a breadth of policy superior to all motives of national prejudice.

As regards the method of supplying and carrying off the power water, it was finally decided to construct a surface canal above the Falls, 250 feet wide at the mouth, and running into the land for a distance of 1500 feet to the site of the power-houses, the latter to contain eventually machinery capable of delivering 50,000 horse-power. A wheel-pit would there be dug to a depth of 178 feet, and connected at the bottom with a tunnel 7000 feet in length, having a slope of 6 feet in a 1000, and a maximum horse-shoe section of 21 feet by 18 feet 10 inches. Water would flow through the tunnel to the outlet below the Falls at a rate of a little less than 20 miles an hour.

The questions of machinery and power distribution were not settled so easily. In the first place, the forms of turbine most popular at that time did not appear convenient for the installation in question; in the second, given a most efficient turbine, how was the 5000 horse-power developed by it to be brought to the surface many feet above? in the third, how was the power, when delivered at the surface, to be distributed in the neighbourhood and at a distance?

The Company did a very wise thing. Instead of sitting down and trying to think the matter out by themselves, they appointed an International Com-

mission, consisting of Sir William Thomson (now Lord Kelvin) as chairman, Dr. Coleman Sellers, of Philadelphia, Lieut.-Col. Turrettini, of Geneva, Prof. G. Mascart, of the College of France, and Prof. William Cawthorne Unwin, Dean of the Central Institute of the Guilds of the City of London. This commission, established in London, was empowered to obtain records of all sorts that should help to solve the three problems now before the Directors of the Company, and to award $22,000 (£4400) in prizes. "Inquiries and examinations concerning the best known existing methods of development and transmission in England, France, Switzerland, and Italy, were made personally by the officers and engineers of the Company, and competitive plans were received from twenty carefully selected engineers, designers, manufacturers, and users of power in England and the Continent of Europe, and also in America." [1]

The first important result of this commission was that Messrs. Faesch & Piccard, of Geneva, were selected to design the turbines. The character of a turbine is probably widely known to the public, but to prevent any possible misconception we may here state that a turbine is composed of a number of vanes set spokewise round an axis, and enclosed in a cylinder in such a fashion that all water passing through the cylinder must push the vanes aside in its course, imparting to them and their axis a circular motion. In order to

[1] *Cassier's Magazine.*

make the water more effective, fixed vanes are attached rigidly to the cylinder walls at a short distance from the moving vanes, so as to deflect the water on to the latter at the most efficient angle. The turbine principle has lately been employed largely with steam to drive torpedo-destroyers and merchant vessels at high speed, and to supply motive force for dynamos and the ventilating fans of mines.

The Niagara turbines are about five feet in diameter, and have a vertical axis. A peculiarly ingenious feature of their construction is that they are made in two storeys, as it were, the top vanes the larger, and that the water from the penstocks, or supply pipes, is made to enter between the two sets. The pressure against the upper vanes being greater than that against the lower vanes, the turbine is endowed with sufficient lifting power to support the entire weight of all the revolving parts, namely the wheels, the vertical shaft, and the revolving parts of the generator driven by the wheel.

The mention of the *shaft* brings us to the second point under investigation—the best means of bringing 5000 horse-power from the point of development to the surface. For this purpose it was decided to employ a shaft of steel tubes 38 inches in diameter, contracting at intervals into a solid bar 11 inches in diameter, to run in journals for the sake of steadiness.

At the upper end of the shaft should be placed—what? The answering of this question demanded the most careful investigation. In 1890 there were people

to plead for four different methods of power transmission. Some could point to the good work done at Schaffhausen and elsewhere by turbines driving manilla and wire ropes; others to Geneva, where turbines transmitted hydraulic pressure for considerable distances through pipes. At Paris, again, the compressed-air system had been largely developed, and in America this method had a stout champion in George Westinghouse, the famous inventor of the air-brake for trains. The fourth method—that of transmission by electricity—could, however, produce the best credentials: a particularly good proof of its reliability being afforded at Domène in the Dauphiny Alps. The power for a paper-mill is there drawn from a glacier in the mountain four miles away, where the power-house is inaccessible for three months of the year. In spite of sleet and snow, and storms and intense cold, the conducting wires do their duty continuously and well, with great profit to the owner of the mill to which they supply power.

As the Niagara plant was to be on an unprecedented scale the dynamos were of unequalled capacity, able to produce currents in large quantities. These generators differed from the usual type in one very important particular, viz., that the position of the stationary and moving parts was reversed at Niagara. It is customary for the armature—a series of coils of insulated wire—to be rotated rapidly inside a circular ring, called the field-ring, to the inner face of which are attached a number of powerful magnets. In the

Niagara installation the armature is fixed, and the field-ring made to revolve. We may assume that the armature in question resembles a huge cake with a large hole cut through the centre. The turbine shaft is extended to pass through the cake and project some distance above it, ending in a taper which fits tightly into a hole in the centre of a horizontal plate or "driver" of rather larger diameter than the armature. The field-ring is bolted tightly on to the edge of the driver, and the shaft, driver and ring have together a decided resemblance to a Chinese umbrella, the turbine shaft representing the handle, the driver the top, the ring the hanging sides. It is a noble umbrella indeed, the carrying of which would need the sinews of a small Celestial army. Its weight is 79,000 lbs., or about 35 English tons; this includes the shaft, the driver, and the ring with its pole-pieces and bobbins, each of which weighs more than a ton. The whole revolves at a rate of 250 revolutions a minute, giving a fly-wheel effect of 1,274,000,000 lbs. One advantage of this arrangement is therefore obvious, that the need of a special fly-wheel, as originally designed, is done away with: another is that the magnetic attraction between the field magnets and the armature acts against the centrifugal force tending to burst the ring, and so increases the "factor of safety" of the ring.

This last is worthy of a few lines to itself. Its diameter is 11 feet 7⅛ inches, its depth about 4 feet. The ring is forged in one piece without weld from a nickel steel ingot, 54 inches in diameter and more

than 16 feet long, through the centre of which a hole was bored preparatory to expansion on a mandrel under a 14,000-ton hydraulic press. The Bethlehem Iron Company was responsible for the forging, and the Westinghouse Electric and Manufacturing Company for the trueing and turning-up on their mammoth lathes.

The Niagara Falls Power Company have on the American shore two power-houses. Each is designed to accommodate ten generators, giving a combined output of 50,000 horse-power. The one is finished and in full working, the other rapidly approaches completion. Beneath the stately row of dynamos, which we see on entering a power-house, yawns the wheel pit, 463 feet long, 20 broad, 180 deep—a huge slot cut out of solid rock. If we are permitted to descend we find men busy attending to the bearings, watching that the oil-supply keeps down their temperature to the proper figure. Near the bottom the turbines hum on their platforms of stout steel girders spanning the gulf, and fling vast quantities of water into the nether darkness, whence it finds a path through a side tunnel into the great main tunnel that occupied 1000 men continuously for more than three years, in the removal of over 300,000 tons of rock, and the placing of 16,000,000 bricks for lining. Near the portal the grade falls very suddenly, so as to permit the discharge of one-half of the flow from the tunnel below the surface of the Rapids.

In the power-house, flanking the generators, stand

two platforms of white enamelled brick, each nearly 20 yards long and some 13 feet wide, surmounted by eight upright stands, on the face of which are many indicating instruments. These structures are technically known as the switchboards, to each of which is conveyed the total 25,000 horse-power from a group of five generators. "The switchboards are the main nerve-centres of the plant from which its various functions are directed and controlled. Upon them are located instruments and appliances by means of which the attendant is always informed as to the output and voltage of the various generators, and which indicate instantly the nature and, within certain limits, the location of any disturbance in any part of the system. . . . In front of the attendant are half a hundred levers controlling pneumatically the great dynamo and feeder switches and auxiliary switches. . . . Here, by a crook of the finger, the attendant can at will cut off instantly the entire supply or any portion of it."[1]

In comparison with the power handled, the number of men required to control it is small. But the well-being of so many thousands depends on the small band in the power-house, that it becomes an absolute necessity for each man to be specially trained, alert, resourceful to meet any emergency that may arise. The working of the generators goes on night and day, and the employés are therefore divided into three

[1] Mr. Philip B. Barton, in *Cassier's Magazine.*

shifts of eight hours each. At the head of each shift is the electrician-in-charge, whose particular duty is to operate the two main switchboards, and his post—the captain's bridge of the plant, as it has happily been called—is switchboard Number One. An assistant electrician has charge of switchboard Number Two; a shift foreman is responsible for the operation of the motive-power plant, having under him oilers to tend the bearings, labourers to keep the inlet racks to the penstocks free from eel-grass, ice and drift, and the man who looks after the elevator in the wheel-pit. Other officials are in attendance to repair the machinery at any point, whether hydraulic or electrical, and attend to the telephone, through which important orders may come at any moment.

The current manufactured by the generators may be used either locally or at a distance. In the former case the pressure, or voltage, is that of the generators, but for transmission to distant places such as Tonawanda or Buffalo, 20 miles off, it would be unprofitable to use so low a pressure, on account of the loss that results from the resistance of the conducting cables. The current is therefore "stepped-up," or increased in intensity, to 11,000 or 22,000 volts, just as water or gas is pumped at very high pressures through long pipes. On reaching the receiving end of the transmission cable it is "stepped-down," or reduced, by transformers for local uses, and converted, if necessary, from alternating to direct current.

Niagara power was first sent to Buffalo in 1896.

The cables are slung on stout poles 35 to 65 feet high, placed about 60 feet apart. Porcelain insulators of unusual size are employed to protect the cables from leakage, and in order to maintain an efficient guard of the line, the Niagara Falls Power Company has purchased a strip of land 30 feet wide reaching from the Falls to Buffalo. The line is patrolled night and day by men who are able to communicate by telephone with headquarters.

At the Buffalo Exposition of 1901 was witnessed the most magnificent display of electric illumination that ever gladdened the eyes of man. The central point of the display was the electric tower surmounted by a superb figure of the Goddess of Liberty. Several hundred thousands of eight candle-power lamps had been arranged along the angles and edges of the building and its chief architectural details. At a given signal the operator in the electricity building started a small motor, controlling a worm gear that slowly poured into the lamps the whole of the power taken from a generator at roaring Niagara, 20 miles away. The gradual change in myriads of lamps from faint luminescence to full incandescence came as a revelation of beauty to the thousands of spectators in the grounds below; and soon after a huge searchlight swept the horizon, even to the mighty cataract from which it derived its force.

The purposes to which Niagara power is already turned are legion. The population of the north-west corner of New York State has become dependent for

many conveniences and comforts on the energy issuing in vast quantities from the grey limestone power-houses flanking the sides of the inlet canal. Four cities, of a combined population of half a million, are lit throughout by Niagara force, which also operates their 350 miles of street-car track. In Buffalo, the Tonawandas, Lockport, and Niagara Falls fifty large manufactories, representing a capital of $100,000,000, depend entirely for their success upon a constant supply of current from the Company's generators. And so efficient is the organisation of the Company's plant that during a period of nearly three years total interruption of power has occurred but once, and then only for eighteen minutes, on account of an ice-jam in the river. As the plant is increased the possibility of interruption will become even slighter, since the switchboards are so arranged that the current from any one group of generators can be switched in a moment into any supply line. The rapidity with which improvements in electrical apparatus succeed one another may be gauged from the fact that, in the second power-house on the American side, the five turbines last put in will be of a fixed field-ring type—an improved reversion to old practice; while on the Canadian side, where tunnel, wheelpit, and intake canal for a capacity of 100,000 horse-power are being completed, the Company is establishing dynamos producing the enormous figure of 10,000 horse-power each. This increase in the size of the unit is, of course, the result of proved economy in

larger generators, as regards cost per horse-power in the construction of the generator, and the turbine to drive it, and the space required in wheel-pit and power-house. It is possible that in the future we shall see far larger generators even than these in common use, for the big thing of to-day becomes the normal practice of to-morrow.

We should at least mention, though full details of management, construction, &c., are not at the author's disposal, an independent company—known as the Niagara Falls Hydraulic Power and Manufacturing Company—which already develops and sells 35,000 horse-power to various industries. This company's power-house is situated below the Falls. It draws its supplies from a canal that connects the upper river with the edge of the bluffs, whence three penstocks, 11 feet in diameter, conduct the water 210 feet vertically to fourteen turbine-wheels of from 2000 to 2500 horse-power each, connected directly to generators coupled at each end. From these generators the current is led to the top of the bank by means of wires and aluminium bars built along the side of the penstocks, and thence in underground subways to various consumers.

With power so abundant it may well be cheap. In how many regions of the world could you, for the sum of $8 (£1, 12s.), obtain from year's end to year's end, without a break, energy representing one horse-power? Having these figures before us we can understand why the Pittsburg Reduction Company, which controls the aluminium industry of America,

left Pittsburg, where good coal costs but *68 cents* (2s. 10d.) a ton, and migrated to Niagara; and how it comes about that many manufacturers can here save enough on power in one year to pay for building and cost of removal.

The Company just named produces pure aluminium —a metal distinguished by its lightness, beauty, and freedom from corrosion—from an oxide of alumina, by smelting the latter in carbon-lined retorts which act as one terminal of a heavy electric circuit, massive carbon rods suspended above the crucibles forming the other pole. The Carborundum Company also employs intense heat—electric furnaces of to-day are used at a temperature of 7000 degrees—to smelt carborundum from its ore into crystals, which are ground into powder and pressed into various forms for grinding purposes as emery, large wheels for shaping tools, or tiny discs for smoothing teeth. Among electrolytic and electro-chemical processes none are of greater interest than the carborundum processes, whereby an artificial abrasive is made in much the same way as that which brought the diamond into existence.

Great factories are springing up for the manufacture of carbide of calcium, and other chemicals. Thomas Edison, the great electrician, has prophesied that Niagara will be "the great electro-chemical centre of the world." It may already claim that distinction, so powerful an ally is an unlimited supply of cheap power to the chemist.

Paper, silver-plate, graphite, lamp, cloth, and steel

factories are rapidly rising within sound of the Falls. Electricity heats the ovens in the huge establishments of the Natural Food Company. At Tonawanda electricity saws and planes vast stacks of timber; at Lockport it whirls heavy trains; at Buffalo it runs the street cars, prints one of the leading newspapers, handles thousands of tons of cereals, helps in the creation of steel bridges, operates refrigerators, supplies the motive power for great dockyards, tanyards, breweries, and pumps.

At Niagara, as a result of this new-born power, a great city is springing up with mushroom speed—a city free from smoke, gas, ashes—an ideally clean city. Five trunk railways lead westwards from it, five to New York, five to Boston. On the completion of its docks Niagara will be the eastern terminus of the Great Lake basin, at the greatest transhipment point of raw material in America. All things augur for Niagara a future comparable to the present of Chicago.

It is a matter for thankfulness that the great power installations have been so arranged as to leave the picturesque beauties of the Falls unharmed. Tourists will still find the huge cataract a thing to gaze upon with rapt admiration, despite the turbines pulsing with mighty energy not far away. The public-spirited action of the Company is further seen in the industrial village of Echota, which they have built for the employés in the factories. A few years ago the eighty-four acres on which it stands was water-logged

meadowland, subject to inundation by the streams that run on two sides of it a few feet below its level. The Company therefore built a high dyke all round it, and, as it was impossible to raise the area to a height at which it would drain readily into the river, they instituted a system of deep drainage which, traversing the city in all directions, discharges into large pits whence the water is pumped into the streams. So carefully has this been done that rains no longer make the earth heavy and muddy, nor does the sun scorch it into cracked clay and dust. Lawns and trees flourish, and wet cellars are unknown. Broad roads intersect the property on a systematic plan, passing between rows of trim houses well provided with modern comforts—running water, electric light, and a wholesome sanitary system. The streets are lit with large clusters of lamps by night. Boughs of trees give grateful shadow by day. A frequent service of electric cars runs at all hours. And last, but not least, rentals are as low as nine dollars a month, light and water included. "The village of Echota has been evolved," writes Mr. John Bogart,[1] "in accordance with the careful study of the men to whom was committed the responsibility of the solution of a complex problem. A district not fit for comfortable residence has been transformed into an ideal healthful village. Ground upon which no vegetation would thrive has been changed to a region of velvet lawns

[1] In *Cassier's Magazine.*

and blooming gardens. Roads which were a discomfort from dust, or annoyance from mud, have been made into well-paved, beautiful streets. An unattractive expanse of poor meadowland has become a model town."

We may here say farewell to the great Niagara Falls, and in conclusion turn our thoughts for a moment to the Zambesi, where the Victoria Falls, twice as broad as those of Niagara, have a sheer drop of nearly 400 feet. To-day, in California, power is successfully transmitted for nearly 150 miles, and with this precedent it is to be hoped and expected that in the future water-power available in unequalled volumes at "the smoke that thunders" will be utilised to aid the development of the great mineral resources of Rhodesia and South-Central Africa, converting what is now semi-explored territory into centres of industry.

Note.—On the Canadian shore there are at present in progress two separate undertakings independent of the Niagara Falls Power Company, viz. the Ontario Power Company, which is now constructing a proposed initial development of 30,000 to 50,000 horse-power; and the Toronto Niagara Power Company, which has recently commenced the construction of a 50,000 horse-power plant.

CHAPTER II

THE TAMING OF THE NILE

To no country in the world does the veil of romance cling more closely than to Egypt, that strange, mysterious land of utter barrenness one jostling prodigal fertility; in which huge monuments tell of great bygone races, and proclaim that here was the cradle of civilisation and the birthplace of history.

To visit and explore Egypt is to visit and explore the Nile, the huge river that has its beginning at the equatorial Nyanzas, and flows northwards three thousand miles before its majestic stream discharges itself into the waters of the Mediterranean. Countless years prior to the advent of man the river hollowed out its bed in the plains and through the rocks of Eastern Africa, struggling with the thirsty Khamsîn-swept desert for a narrow strip of verdure on which mankind might dwell. In course of time the Land of the Nile teemed with a great population that conquered surrounding peoples and left records of their victories, their religion, and their kings in the temples and tombs that line each bank of the river. Its waters were the scene of many a great pageant. In the temples hard by the Egyptians did reverence to the bounteous Nile, the giver of all good things to

From a photo by] [*Sir John Aird & Co.*

A General View of the Great Nile Dam from the East.

The Dam is $1\frac{1}{4}$ miles long, stretching from shore to shore in a straight line.

[*To face p.* 34.

them, under the name of Osiris, the God of Life, in eternal combat with his murderer Typhon, the demon of the desert and personification of Evil itself.

From the uncertainties of history that begins with the very beginnings of history the Nile flows out, the life-blood of countless generations that have been and of many more to come. It does to-day what it did in the days of Rameses and Cheops, of Cambyses, Alexander, Julius Cæsar, and Napoleon. The great conquerors who have floated on its bosom are turned to dust, but still every year is seen the wonder of the flood rising in summer heat under a cloudless sky overflowing its banks till the adjacent villages are but as islands in a watery waste, covering the land with its fertilising silt, and then gradually sinking into its bed again. The year is divided for the Egyptian into three seasons: Summer, when the Nile dwindles to its lowest level; Flood-time, during which the melting snows of Abyssinia and the incessant tropical rains of the Nyanza basin, thousands of miles away, roll in increasing volume down the valley, laden with the rich red silt of the Atbara; and Winter, when green crops come up as if by magic on the sinking of the flood, and the corn crops are sown for the harvest in March.

The anxiety with which the rising of the Nile is watched may be appreciated by those who have experienced a season of drought in climes usually blessed with an abundant rainfall. They, however, keep their eyes fixed on the heavens for the clouds

that are long delayed, or roll over without shedding the dew of heaven; the Egyptian looks at his feet, watching the rise of the waters. The Nilometer is the arbiter of his fortunes. The ordinary rise at Cairo is about 24 feet, less is insufficient, more brings danger. A rise of 18 or 20 feet spells famine; a flood of 30 feet means ruin.

The silt, deposited at the rate of some 5 inches a century, is of an extraordinary productiveness. "Wherever the soil is fairly cultivated and properly watered, it amply repays the toil of the husbandman, yielding luxuriant crops of tobacco, cotton, sugar-cane, and indigo. Among the shallows of Lake Menzaleh lingers the once-prized papyrus. In the beautiful valley of Faioum myriads of roses burden the air with fragrance; and every peasant's tiny nook of ground affords a supply of leeks, garlic, melons, and cucumbers."

Acres of sunny corn-fields are contiguous to the eternal barrenness of the desert. It has been truly said that if the soil of Egypt be but tickled with a hoe it will laugh with a harvest; a quality that has made it, like India, the scene of much contention for its possession.

During a great part of the year the Egyptian is like a man ushered into a treasure-house from which he may carry only what his hands can hold. The Nile flows past his home in vast volume, amply sufficient for the needs of the whole country were it but available in a constant supply and in all spots of the

long, narrow valley that is the true Egypt. For centuries, at low Nile, the farmer has been obliged to ladle water painfully to upper levels by means of the primitive "shadoof," or pole-bucket, and discharge it into the myriad canals and ditches that intersect his property. The English farmer is happy in being able to exclude from the list of his burdens that of lifting water on to his land at the cost of some fifty shillings an acre. "It will be seen," says Sir Benjamin Baker, "what a vast amount of human labour is saved throughout the world by the providential circumstance that in ordinary cases water tumbles down from the clouds and has not, as in Egypt, to be dragged up from channels and wells."

Now, though the Egyptian is probably doomed to expend a great portion of the sweat of his brow on this task of watering, Western science has come to the aid of the "unchanging East." The same necessity that drove the ancient Pharaohs to the construction of canals and reservoirs has, during the last half century, exercised the thoughts of those responsible for the welfare of Egypt. The scheme has been gradually evolved of putting a bridle upon the Nile, to check its course somewhat during flood-time and rescue some of its surplus water from the Mediterranean against the season of greatest need. To a Frenchman, Meugel Bey, belongs the honour of having first spanned the stream, below Cairo, with a barrage. This work consists of two brick arched viaducts crossing the Rosetta and Damietta branches

of the Nile, containing 132 arches of 16 feet 14 inches span, which are closed during the summer by iron sluices, so as to retain on the upper side a head of 15 extra feet of water, to be thrown into the main irrigation canals below Cairo. The building of the barrage occupied fifteen years, and another twenty passed before it could be considered in satisfactory working order. The chief difficulty of construction arose from the unstable nature of the matter below the foundations, through which the water forced its way, despite the timber pilings driven deep down into the river-bed. At a later date Major Brown, Inspector-General of Irrigation in Lower Egypt, found it expedient to relieve the pressure on the old barrage by constructing auxiliary weirs below it, and so raise the water level on the lower side. He effected this by dropping cement rubble from rafts into a movable timber caisson, thus forming solid and contiguous masonry blocks from bank to bank.

The effect of Meugel Bey's great work, hampered by the whims of Egyptian officials, and costly in spite of forced labour, has been immensely beneficial to Lower Egypt. This is sufficiently proved by the fact that in 1900 it saved the cotton crop in the Delta from utter disaster, and, according to Lord Cromer's calculations, has doubled the cotton crop of Egypt, an annual gain of £5,000,000. To give the reader an idea of the water-retaining capacity of the barrage, it may be mentioned that it feeds six canals, the largest of which, the central canal, at the apex of the Delta,

carried, even in the drought of June 1900, a volume one-fourth greater than that of the Thames in mean flood; and the Ismailieh Canal, running to the Suez Canal, was still a river twice as large as the Thames at the same season.

The steamer, or picturesque dahabeah, after passing through the huge barrage locks on its way upstream, encounters no obstruction for 250 miles, when it reaches Assiout, the thriving capital of Upper Egypt, lying in a fertile plain at the foot of the Libyan Mountains. Here is the second step in the staircase of the Nile water-scheme, the recently erected barrage, rather more than half a mile long, and pierced with 111 arched openings 16 feet 4 inches wide, all of which can be closed by steel sluice-gates. The barrage measures about 50 feet from front to rear at the base, and 47 at the top, along which runs a roadway from shore to shore. The whole rests upon a platform of concrete and masonry 87 feet wide and 10 feet deep, which is protected from the undermining influence of the water by tongued and grooved iron sheets driven down 23 feet into the river-bed, made tight at their joints with cement. As a further precaution a strip of the bed both up and down stream is covered for a width of 67 feet with stone pitching, resting on clay puddle and layers of fine gravel and pebbles respectively. So that, supposing a small quantity of water to have penetrated the clay on its upper side, and worked its way right under the two fences of iron sheets, its upward course is

severely checked, if not annihilated, by the sand reinforced by pebbles in turn held down by stone blocks.

Work was commenced at Assiout on December 1, 1898, in the formation of "sadds," or dams, surrounding the site of the foundations on the western side. By February in the following year everything was ready for pumping the water out of the sadds. An area of 13 acres being laid dry, men were crowded on to drive piles, lay the cement and rubble foundations, and build the masonry on them. The next year further sadds were made on both sides of the river, fresh foundations laid, and the first section continued. In 1900, which witnessed nearly one half of the entire work, the sadds met in mid-stream, and navigation was diverted to a gap purposely left near the east bank. The following figures will give an idea of the scale of operations during this year: in May and June the average number of men at work was 13,000, nearly a million and a half sandbags were placed in position, more than 100,000 superficial feet of iron piling driven, over 90,000 cubic yards of masonry and foundations laid, nearly half a million cubic yards excavated and filled. To keep the water down in the sadds 17 pumps, each throwing a solid column of 12 inches, were constantly employed, in addition to many auxiliary pumps.

The barrage was completed in the spring of 1902. will, it is estimated, bring under cultivation an additional 300,000 acres, supplying their needs by

means of the great Ibrahimiyah Canal, which receives water just above the barrage; and will render more effective the work of the Cairo barrage.

Three hundred and fifty miles above Assiout the Nile is once more spanned at Aswân by the huge dam which will for centuries be monumental evidence of the enterprise of English rulers and of the skill of English engineers.

Aswân, or Assouan, signifies "the opening." Its ancient name was Syene; and as such it had fame as the depôt of merchandise passing from north to south, as a strategic position at the gates of Nubia, and as having in its neighbourhood famous quarries, whence came many of the colossal structures of old Egypt. The first of the seven so-called cataracts—they are really no more than rapids—of the Nile, until recently shot between the rocky islands which here unite with the towering cliffs that press in towards the river on either side. The cataract fell in three stairs, of which the uppermost was the most formidable; and boats going upstream had to be towed through rushing waters by gangs of half-naked Arabs. A writer has thus described the scene: "The Nile, bending abruptly, broadens into a kind of bay, which is shut in by the green and lovely island of Elephantine, whence an early dynasty of Egyptian kings derived their name. The high, bold rocks which rise on every hand seem like the boundaries of a lake. On the left, nestling under crags, whose summit is crowned with ruins, lies the modern village; in the

distance the yellow sandy hills are covered with the remains of Saracenic architecture. To the right the shattered walls of a convent mark the crest of a sandstone eminence; and all around between the desert and the river, the palm groves cluster in verdurous masses. . . . The view from the environing rocks is very striking, a view of hill and water, wood and lowland; and beyond, the confused and blown heaps of the rolling sands of the desert. The river hurries past in a succession of rapid eddies and foaming whirls. In their midst lie various black-coloured islets, marking the boundary of the cataract."[1]

Above the cataract is the island of Philae, the Mecca of the ancient Egyptians, who there worshipped at the shrines of Osiris, Isis, and Horus, the sacred triad of their mythology. In the bed of the cataract, so the story ran, lay the body of the murdered Osiris, to rise every year in the form of the life-giving flood; so what spot more fit than Philae in which to raise magnificent temples to him, his sister-wife, and son? Huge ruins still crown the island, colossal propylons, shadowy arcades covered with hieroglyphics; gigantic columns, obelisks, and statues, forming so wonderful a testimony to Egyptian art that modern travellers visit it with an eagerness akin to that of the old-time worshippers.

For the last five years the iron-bound precipices that form a stern setting to the lovely island have

[1] W. H. Davenport Adams in "The Land of the Nile."

looked down upon a mighty struggle between Man and Nature. For in the heart of the cataract, where the waters rush at a speed of fifteen miles an hour, has been raised a huge dam from hills to hills, offering a broad breast of enormous strength to the hurrying Nile. Surely imagination kindles at the thought of men, so small and weakly, bridling a prince among the rivers of the world, despite the silent, unceasing hostility of the watery element!

To begin the story of the Nile Dam aright we must go back to the day when Sir Samuel Baker first suggested that here, at the "Gate" through which the fertilising flood rushes with maximum force, should a gate of masonry be placed. He conceived the idea of a series of dams to form reservoirs from Kartoum downwards. "The great work might be commenced by a single dam above the first cataract at Aswân, at a spot where the river is walled in by granite hills. By raising the level of the Nile 60 feet obstructions might be buried in the depths of the river, and sluice-gates and canals would conduct the shipping up and down stream."

After forty years Sir Samuel's proposal has been carried out almost to the letter. Mr. Willcocks, formerly Director-General of Reservoirs in Egypt, worked at the idea of constructing such a dam for years, and after surveying all likely points in the valley, came to the same conclusion as the great explorer, that Aswân was the most suitable spot. An international Committee, consisting of Sir Benjamin

Baker—already famous for his work on the Forth Bridge—Signor Giacomo Torricelli, and M. Auguste Boulé, to whom the matter was referred, also arrived at the same opinion. Mr. Willcocks accordingly drew up plans for a dam, or rather series of curved dams, capable of holding back 3700 million cubic metres of water. The project unfortunately involved the submersion and destruction of the ruins on Philae, and on that ground was so vigorously opposed, that fresh designs were made, and a single straight dam substituted of such a height as to retain 1065 million cubic metres—or less than one-third of the original estimate.

The dam is of a most impressive size. From end to end it measures a mile and a quarter. Its maximum height from lowest foundation to parapet is over 120 feet. On the upstream side it is perpendicular, on the downstream side it thickens downwards from the summit, where it has a width of rather more than 16 feet, with a regular batter of 1 in $1\frac{1}{2}$, which in its deepest parts gives it a foundation breadth of 100 feet. The total weight of masonry is over 1,000,000 tons. No less than 180 openings pierce it from face to face. Of these 140 are 23 feet high by 6 feet 6 inches broad, and the remaining 40 are 12 feet high and of equal width. These openings are closed at their upstream ends by steel sluice-gates, working mostly on the Stoney roller principle, which enables them to be opened by hand even when subjected to a pressure of 450 tons. When open they will pass

the entire volume of the Nile in full flood at the rate of 15,000 tons per second. The water levels on the dam faces differ at the beginning of summer by 67 feet; and this head of water forms a lake 150 miles long, that would reach from London to Nottingham and still leave enough over for Thirlmere.

Sir Benjamin Baker, the consulting engineer to the Dam Construction Committee, said in a paper read at the Royal Institution, that the quantity of water stored in this artificial reservoir may be made to appear enormous or trifling according to the standard to which it is compared. Thus, on the one hand, when we consider that the rainfall within the four-mile cab radius from Charing Cross amounts to 100 million tons annually, we become aware of the insignificance of the reservoir as a substitute for a rainfall such as ours over the whole land of Egypt. But, on the other hand, when calculation shows that the reservoir holds enough water for a full domestic supply to every one of the 42 million inhabitants of the British Islands, then the vastness of the quantity becomes appreciable. And it increases our respect for the Nile to learn that in flood-time a volume of water equal to the total contents of the reservoir passes through the sluices every twenty-four hours.

As soon as the initial difficulties regarding finance had been overcome by the timely aid of Sir Edward Cassel, tenders were invited for the construction of the dam. Sir John Aird & Co. were the successful competitors; and in February they signed a con-

tract, including Messrs. Ransomes & Rapier as subcontractors for the steelwork, to complete the dam by July 1903. The foundation stone was laid by H.R.H. the Duke of Connaught on February 12, 1899, and the dam formally opened by His Royal Highness on December 10, 1902, or eight months in advance of contract time. The merit of this feat is enhanced by the unexpected difficulties that the constructors were called upon to cope with from time to time.

Even the expected difficulties were formidable enough. "It would not be too much to say," writes Sir Benjamin Baker, "that any practical man standing on the verge of one of the cataract channels, hearing and seeing the apparently irresistible torrents of foaming water thundering down, would regard the putting in of foundations to a depth of 40 feet below the bed of the cataract in the short season available each year as an appalling undertaking." But everything had been carefully thought out, and in a short time after the signing of the contract, a large tract of the desert adjoining the desert was taken possession of, and on it rose railways, houses, offices, machine-shops, stores, and hospitals. Soon thousands of natives and European workmen transformed the solitude into a busy town.

The islands across which the dam runs were submerged at flood-time, but in summer only a few channels passed the water. These, naming them in order from east to west, are: the Bab-el-Kebir, the Bab-el-Harum, the Bab-el-Saghaiyar, the Central

Channel, and the West Channel—the last two the widest. Through them the water rushed at a pace exceeding the fastest progress of a University crew The question arose how to block these channels in such a manner that the site of the foundations could be pumped dry. Recourse must be had—as at Assiout—to "sadds," but under very different conditions. It was therefore determined to build stone sadds at the lower end of the channels from island to island, before high Nile, and, when comparatively still water had thus been secured above them, to form sand-bag sadds at the entrances; so that when the flood had subsided pumping operations might be at once begun.

The Kebir, Harum, and Saghaiyar channels were attacked first. Huge stones, weighing up to four tons, were lowered into the current by cranes; but such was the momentum of the water that even they were carried away. It was therefore found necessary to enclose several blocks at a time in large nets of steel wire; and on occasions when this method proved ineffective the engineers adopted even more heroic measures, and shot into the stream railway trucks laden with granite blocks lashed tightly together by wire ropes. These masses, weighing upwards of 50 tons, acted as a "toe," or lodgment, for smaller bodies, and at last patience was rewarded by the appearance of the temporary dams above the surface. Cement and sand were then tipped in on the upstream side to work in among the stones and fill all interstices. The completed stone sadds were

22 feet wide on top, thickening rapidly downwards to a maximum depth of 50 feet.

Full Nile put them severely to the test; for after its subsidence steel rails were found strangely twisted, and the surface of the stones was like that of polished marble. As soon as the summits were exposed by the sinking flood, huge numbers of sandbags were thrown into the entrances of the channels, forming dams 16 feet wide at top and 55 deep. Since the flood of 1899 was unusually low, the temporary dams were carried across the ends of the Central Channel as well, and completed in February 1900.

Pumping then commenced. Many large 12-inch centrifugal pumps got to work and, as Sir Benjamin Baker admits, the engineers watched the result with great anxiety, as no one could predict whether it would be possible thus to dry the river-bed. Fortunately for the progress of the dam, the sadds stood the test remarkably well. In one day the Bab-el-Kebir was emptied of all but a small leakage easily nullified by a single pump; the Bab-el-Harum, the Bab-el-Saghaiyar, and the Central Channel being equally amenable. By March 1900 the contractors were hard at work on the excavation of the drained surfaces, cutting down until hard, firm rock was reached. Great trouble resulted from the fact that in three channels an unexpected depth of schistous formation had to be removed. The Bab-el-Kebir especially furnished a great quantity of extra work, inasmuch as the rock had to be excavated to

a point 38 feet below the level of the contract drawings, and the "batter" of the walls being maintained of necessity, the foundation breadth at this place was 100 feet instead of about 70.

This delay, as serious as it was unexpected, aroused the contractors to tremendous efforts to make up for lost time, and raise the masonry to a sufficient height before the following flood-time. In June work was carried on day and night, brilliant arc lights replacing the sun at sunset.

A contributor to the *Daily Mail* has graphically described the scene:

"Orders are given for all workers to assemble at 6.30 for 7 A.M. duty. At seven the engineer takes his coffee and roll, lights a cigarette, and is swiftly driven to his work by fleet runners from his own door, and landed practically in the centre of activity.

"Arrived on the barrage, or dam, a knot of "sheikhs" and "reis" greet him with the courtly Eastern salaam, and shortly after may be seen speeding towards the various quarters of the works. Maybe 1000 men are at work, each section under its particular chief, the fellaheen from near Cairo, famous stone-dressers and masons for centuries back—so far back that the vista of ages grows dim; these are attended by boys in picturesque "galabeahs," carrying water, and very often by women gracefully bearing boxes of "homrah," or mortar, on their heads. Bedouin and fellaheen work like ants at the rough work, and dark-skinned, smiling, good-natured Sudanese ram

the concrete as it is placed in position, as if they took the whole thing as a huge joke.

"As the work proceeds one presently hears the Arabs and Sudanese (once, and not long ago, masters and slaves, as the remains of the Cairo slave-market, now in ruins, testify) chanting some of their melancholy and weird dirges, throwing great heaps of undressed stone from one place to another, which, as one looks, becomes spread out into the evenness of a revetment wall, or, neatly dressed, becomes the facing of the dam. Here and there, under broad sun-helmets, like tall mushrooms, may be found a wily Greek or excitable Italian, acting as a useful lieutenant to, and directing the work being executed by, the solitary Englishman perched yonder on an elevation of masonry, apparently an idle spectator, and yet seeing all, and occasionally acting as judge in the many disputes arising between the different factions.

"Ceaselessly the work goes forward, drowned by the equally ceaseless chant, till twelve noon, when up goes the Egyptian flag to the top of the flag-pole, and work ceases until one P.M. Away fly the Europeans on trolleys, the "reis" and "sheiks" on donkeys, to their homes for dinner, and the long-wished for "drink" poor Steevens so well described. The trolleys, propelled by gaily-clad runners, shouting "Oh, ah, riglak" ("Mind your feet!") at the top of their lungs, till one wonders where the breath is coming from for the next call: a company of red and white

By kind permission of] [*Sir John Aird & Co*

Two of the 180 *Sluices in the Great Nile Dam.*

During "high Nile" over 1,000,000,000 cubic metres of water rushes through the sluices daily; or 15,000 tons per second.

[*To face p.* 50.

turbans move off to one spot, another of close-fitting brown skull-caps, representing the fellaheen, tear off, scampering like children, to another locality, and the rear of this motley crowd is generally brought up by the more dignified company of inky-black Sudanese, who at once seek the encampment where their wives are (without whom they never travel any distance).

"Amid ceaseless chattering and gesticulating a hearty meal is made—off what, ye British workmen? Simply a few cucumbers or turnip-tops, two or three lettuces, perhaps; and this, with a bowl of lentils, and the puffed-out flat cakes of the East, washed down with muddy Nile water, constitutes for them an excellent meal. Possibly, if in season, a piece of sugar-cane fulfils the same object. This lordly repast being over, the chattering ceases, the burnooses are brought out from a pile, spread over their bodies, face and all, and they sleep till two o'clock.

"By 2.5 P.M. all hands have fallen to again, to work without break till 5.30 P.M., with the blazing sun overhead blistering all that it touches. Still the ceaseless 'chip-chip' of the mason, the thud of the rammers, the clank of the divers' air-pumps, the monotonous sing-song, and the shriek of diminutive railway engines, till the magic hour of 5.30, when up goes such a shout from the throats of 1000 men as might raise their departed ancestors for generations back, and the shrill 'lu lu' of the women, and the Egyptian crescent once more floats in the cool evening breeze.

Hundreds of devout worshippers drop about in all directions, having spread their prayer-mats, turn their faces to Mecca, and give their fervent thanks to Allah, swinging backwards and forwards like the stalks of a cornfield.

"Then takes place one of the most interesting functions of the day. On a strip of sand left dry by Father Nile, three or four circles of crouching figures are formed, with a 'reis' in the centre of each, and every fifth man sitting forward receives the pay of the five from a large bag of coin, and distributes it directly after; meanwhile the scribe, generally a Copt, standing at the elbow of the paymaster, ticks off the payees' names. As each circle is paid off it dissolves into a crowd of happy children making for the bazaar, there to indulge in the nightly fantasia and the everlasting tap of the tom-toms. . . .

"At the hoisting of the flag at 5.30 P.M. a solitary figure is rowed away down the old river, the headpiece and mover of this vast machinery of humanity, and if one could look through the lattice window of his room two hours after, one would see a picturesque group of gaily-dressed Arab sheikhs and reis standing round that one man of a foreign race making reports and receiving them till midnight strikes, when this representative of the Dominant Power encloses himself within his mosquito curtains with a 'Kullu khalass el naborda kullu leyleh,' and the height of the dam has risen two feet within the last twenty-four hours."

By the end of 1900, the most momentous year in

the history of the dam, the back of the work had been broken. The amount of excavation then amounted to 577,515 cubic metres, and the masonry to 239,468, or about two-thirds of the whole. In the following year the west channel was closed, and foundations were laid up to the western shore, where they met the northern end of the great navigation lock, which is in itself a large piece of engineering.

The lock contains four steps controlled by five huge gates 32 feet wide and 60 feet high. Instead of being placed in pairs, meeting at an angle in the middle—as in river locks of the usual type—these gates are hung from the top on rollers, and slide sideways like a coach-house door into recesses in the flank of the lock. This arrangement was adopted for safety's sake; the two uppermost gates being made sufficiently strong to withstand the whole head of 67 feet of water if suddenly called upon to do so.

At highest flood the ruins on the Island of Philae are partially submerged, and a general saturation of the silt and mud, of which the island is composed, takes place. Measures were therefore taken, under the superintendence of Dr. Ball and Mr. Mat Talbot, to protect the monuments from the risk of settlement, by underpinning the most important parts down to solid rock, or at least to a point below the saturation level. So that we may hope that for many years to come modern engineering, as represented by the colossal dam, may not be blamed as the destroyer of ancient art.

When the river is rising the sluices will all be opened to permit the free passage of the silt-laden water. After the flood, when the discharge of the Nile has diminished to 2000 tons a second, the sluices will gradually be closed, and the Nile slowly mount the upper side of the dam. In May, June, and July the water will be doled out to the farmers. Huge though the storage is it is not abundant, and in order that those enjoying it may be fairly treated, the Government of Egypt has bound down the population to a long list of most elaborate regulations, which forbid even the drawing of water in buckets except at the appointed time.

Already schemes are under discussion for additional dams further up the Nile to extend the benefits conferred by the works here described. The revenue and prosperity of Egypt are so closely bound up with the question of water, that with men of the stamp of Lord Cromer and Sir William Garstin at the head of affairs, we may look at no distant date for new developments possibly approaching in importance the construction of the Great Nile Dam itself.

CHAPTER III

DAMS AND AQUEDUCTS

PROBABLY few of us whose houses are connected with a public water-supply give much thought, as we watch the crystal-clear liquid issuing from a tap, to the journey that it has taken from the point where man first gathered it for his own. Yet, perhaps, it has come many a mile through pipes and tunnels, been flung into reservoirs, strained, filtered, passed again into pipes, first for the town, then for the street, lastly for the house, until, still fresh from its mountain stream or subterranean cave, it emerges into the unromantic surroundings of the bathroom or back-kitchen.

Our direct experience of the mechanical side of a water-supply is usually confined to the operations so often seen in the minor veins that multiply towards its urban extremity. We know only too well the doings of the plumber, and of the labourer who converts the smooth surface of our roads into a dangerous succession of hills and valleys. The consequent bills and rates are apt to blind us to the real romance and magnitude of the work needful to give us our daily water. We must trace the system backwards from our doors, through mains of increasing

size, to the very heart and arteries, before we realise how nobly the brain of engineer and muscle of artisan have been employed, in the cause of health and sanitation, on undertakings about which but a few of those who are directly benefited possess more than a shadowy knowledge or proper appreciation.

Those wonderful old builders, the Romans, have shown us, by the stately march of their aqueducts across plain and valley, that the question of a good water-supply for large towns pressed even in their days. Since then the problem has become increasingly difficult in thickly-populated countries, on account of the artificial contamination of streams and strata by the processes of manufacture. And while, on the one hand, we see the engineer driven further afield for his source of supply, on the other we notice that the demand for an ever greater consumption per head is pushed vigorously by common-sense and scientific consideration.

The daily supply of London has reached the enormous total of 200 million gallons, drawn from the New River, the Thames, and subterranean sources. During the last few years the Metropolis has experienced the inconveniences and dangers of a water-famine, which have turned mens' eyes to schemes discussed in 1866, of tapping the waters of the Welsh valleys, collecting it in huge reservoirs, and bringing it across country by pipe-lines 180 miles long, at a cost of £12,000,000; or of pressing into the service

the Westmoreland lakes, with their available storage of some 36,000 million gallons, and connecting them with London by 270 miles of pipes, at an outlay of 13½ million pounds.

For their boldness these schemes may compare with that of the Parisians to fetch supplies from the Swiss lakes, across 300 miles of France. At present, none of these projects have come to anything; and the first two have let slip an opportunity, since Manchester now draws from Thirlmere, and Liverpool and Birmingham from the Welsh area earmarked for London.

In the following pages it is proposed to describe at short length the construction of the huge pipe-lines that help to supply our three largest provincial towns.

We will first turn our eyes to Thirlmere in Westmoreland, a picturesque little lake of a natural area of 328¼ acres. Previous to 1894, the great cotton city drew its water from Longdendale, a valley situated about eighteen miles east, through which flows the river Etherow, one of the principal tributaries of the Mersey. The reservoirs, of a storage capacity of some 6000 million gallons, collect the water of 19,000 acres, and deliver about 25 million gallons a day to the inhabitants of Manchester. The rate of consumption increased so rapidly between 1856 and 1875 that the Corporation foresaw a shortage unless a further area were laid under contribution; and after an examination of various sources, it adopted a scheme for impounding

Thirlmere, and leading its waters 96 miles to the great reservoirs at Prestwich.

An Act of Parliament authorising the scheme was obtained in May 1879; and six years later the glens of Westmoreland began to resound to the snort of engines and clink of hammers. A huge retaining wall gradually rose across the north end of the lake, where it found an outlet into the St. John's Beck. The dam is divided into two portions by a small rocky eminence, through which surplus and compensation water is discharged by means of a tunnel 12 feet wide and 9 feet high. This tunnel is closed by a transverse masonry wall, pierced with two 36-inch, and one 18-inch pipes, controlled by valves actuated by hydraulic and hand-power.

The dam is driven down throughout its length to solid rock, reaching a maximum depth of 50 feet below the river-bed; at which point, as it rises 50 feet above the lake, it has a height of 100 feet.

The increase of depth in the lake thus artificially produced gives a total storage capacity of 8,130,686,693 gallons; but for present purposes only 20 feet of extra depth is necessary for the supply of Manchester. As occasion dictates the level of the overflow will be raised, and a larger body of water impounded.

The most interesting part of the scheme is the Aqueduct, which brings the limpid stream from under the lofty crest of Helvellyn to a point four miles outside Manchester.

The Romans, to whom iron piping was unknown,

led their aqueducts across valleys on tiers of arches, built at the cost of much labour. The modern engineer is able to adopt the simpler method of gravity-flow. By means of syphons he takes the water down one side of a valley and up the further slope to a point where it finds its own level, and continues its onward course in a gentle fall towards its destination. These long pipe lines are not hermetically sealed from end to end like the service pipes of a town, for in the case of a large total drop between the source and point of final delivery there would be an excessive pressure in the syphons at the valley bottoms, the pressure increasing in proportion to the difference in height above sea-level between the inflow and the lowest portion of the pipe syphon. The engineer, therefore, after determining the "hydraulic gradient," or rate of fall,—in the Thirlmere aqueduct 20 inches per mile—maps out the course of the pipe line in such a manner as to ensure a certain amount of fall between the ends of the syphons, and by placing the upper end of each important syphon on the hydraulic gradient, makes it hydrostatically independent of the rest of the pipe line as regards pressure. The greatest pressure in the Thirlmere aqueduct occurs at the bridge over the river Lune, where the lowest pipes of the syphon have to support a hydrostatic stress of 410 feet, equivalent to 180 lbs. to every square inch, and therefore are $1\frac{3}{4}$ inches thick.

Another important consideration is the tendency of any fluid or gaseous body enclosed in a pipe under

pressure to straighten out that pipe. This effect may be noticed in the flexible tube connecting an air-pump with a pneumatic tyre. At each stroke the tube gives a "kick," unless it be carefully laid in a straight line. The sharper the curves, the greater is their resistance to the flow of air, and the more pronounced is the resultant kick.

It therefore becomes very necessary for the engineer to lead his pipes in as gentle curves as possible, both vertically and horizontally, and at unavoidably sharp bends to anchor them securely to a stable foundation. At the bridge over the Lune, the straightening pull is equivalent to a pressure of 54 tons, which is counteracted by steel straps passed over the pipes and attached to stout anchorages.

On the steep descents on the sides of valleys any slipping of the pipes is prevented by projecting rings which engage with a surrounding bed of concrete.

The Thirlmere aqueduct is made up of three classes of construction: tunnel, 14 miles; "cut and cover," 37 miles; pipe lines, 45 miles. The tunnels, which were bored out by pneumatic drills, are 7 feet wide and 7 feet 1 inch high, and lined where necessary. The cut-and-cover lengths have a transverse section of the same dimensions, and a lining of concrete 18 inches thick. Manholes and ventilators are placed every quarter of a mile. Both tunnels and cut-and-cover lengths will accommodate the ultimate maximum flow of fifty million gallons, but in the metal lengths the channel is divided into five parallel pipe lines,

each 40 inches in diameter, and capable of passing 10,000,000 gallons daily; with the exception of all pipes within nine miles of Thirlmere, where the five-fold line is replaced by a three-fold of 48-inch pipes. In the first instance only one line was laid; and the others will be added as need arises.

The aqueduct, after leaving the lake at the southern end, plunges into Dunmail tunnel, 5165 yards long. Then through a succession of small tunnels to that of Nab Scar, 1418 yards long. After traversing Skeghill (1243 yards) and Moor Rowe (3040 yards) tunnels, it is mostly in pipe and cut-and-cover—the latter a trench dug to the gradient level, floored and walled and roofed with concrete, and covered in again. Before reaching Manchester thirty depressions have to be negotiated by syphons of varying depths. As it is at these points that the greatest danger from bursts occurs we may notice the precautions adopted—which precautions apply in part to the Liverpool and Birmingham Aqueducts.

The most likely point for a burst is naturally at the lowest portion of a syphon, where the pressure is greatest. As a matter of fact, only a very few bursts have ever occurred. But the possible damage resulting from a large body of water let loose suddenly on a country side is so great that the engineers have taken elaborate measures to reduce such effects to a minimum.

At the north or upper end of each of the Thirlmere line syphons is a well divided into two main com-

partments by a wall. The south compartment is subdivided into three or five divisions, according to the number of pipes supplied, and each of these divisions is connected with the north compartment by a pipe, the open ends of which are flush with the floors. In the north compartment are a number of large bell-shaped vessels, 56 inches in diameter, each of which is suspended, small end downwards, from a lever 18 feet long, having at one end a fulcrum and at the other a float, supported by the water of one of the southern divisions. In case of a burst in any one of the syphon pipes the water in its particular southern division at once sinks rapidly, causing the fall of the float; and the motion, transmitted by the lever to the bell-barrel, lowers the latter into the mouth of the corresponding pipe, and so cuts off supplies from the burst syphon. The rise in the northern compartment is neutralised by a number of overflow orifices, which conduct the surplus water into a specially prepared channel until such time as the supply is lessened at the Thirlmere end.

The water in the syphon has still to be reckoned with; and as two of the syphons are over nine miles long the body of included water is very great. In the northern leg of each syphon is therefore stationed a valve—or a succession of valves at intervals—released automatically by an abnormal rate of flow. Briefly described, the valve consists of a metal disc, connected in its central line with two trunnions protruding through the walls of the pipe. At the outer

ends of the trunnion are pulleys, actuated by chains, to the extremities of which heavy weights are attached. One of the chains, after passing round its pulley, is linked to the end of a piston-rod connected with a piston working in a cylinder full of glycerine and water. Above the pipe is an air-chamber, bolted down to a circular orifice, so that there is an air-tight joint between the chamber and the pipe. Athwart the chamber and through its walls runs a shaft, from the centre of which depends into the water-way a lever, carrying at its lower end a metal plate 21½ inches in diameter. At one end of the shaft—outside the chamber—is an arm so weighted that the pressure of water on the plate is just counterbalanced, and the latter maintained in a horizontal position. When a burst occurs the plate is pushed in the direction of the flow, moves over the lever to which it is attached, and communicates the motion to the shaft, which releases a second lever that in turn releases the trunnion chain-wheels and permits the weights to rotate the wheels, and gradually bring the internal valve-disc from a horizontal to a vertical position, completely closing the water-way. The reader has probably noticed the noise of a "water-hammer" resulting from the sudden closing of a tap somewhere on the house supply. The running water, abruptly checked, expends its impetus on the walls of the pipe with a sharp rap that may be heard for a considerable distance. The effect of such a water-hammer on the great pipe lines would be

disastrous; and it is to ensure the very gradual cutting off of the water that the cylinder mentioned above is employed. At the moment when the chain-wheels are released a small cock in a pipe leading from the cylinder is also opened, and the contents slowly escape, permitting the weight attached to the chain to pull round the pulley at a uniform speed.

The danger of a "water-hammer" on the southern or lower leg of a syphon is not so great, as the direction of the rush is the opposite of that of the normal flow. So that for an appreciable time after the burst the water is almost in a state of rest, from which it gradually attains a reverse motion. To check its downward flow check-valves are placed—three flaps, one above another, opening only in the direction of normal flow. On a burst occurring, they at once shut against their seats, and remain there until the syphon is refilled and the flow resumed.

The charging of a syphon is not so easy a matter as might be imagined. The sudden influx of a full column of water might imprison air in the lower parts, compress it, and cause it to burst suddenly up the lower leg, leaving room for a violent rush of water in its track.

An ingenious provision for the charging has therefore been made. In each of the large plugs in the syphon wells is a smaller central one, which is opened by means of a lever of U section, supported at a short distance from one end on a fulcrum which rests on the main lever between plug and float. A

heavy iron ball, weighing 90 lbs., runs in the channel of the short lever. When the central valve is opened the southern end of the lever is depressed, and the ball remains there until the syphon is full, when the float rises, and by raising the main and small levers causes the ball to roll along its channel and close the central valve. The large plug is now watertight and ready for the next emergency.

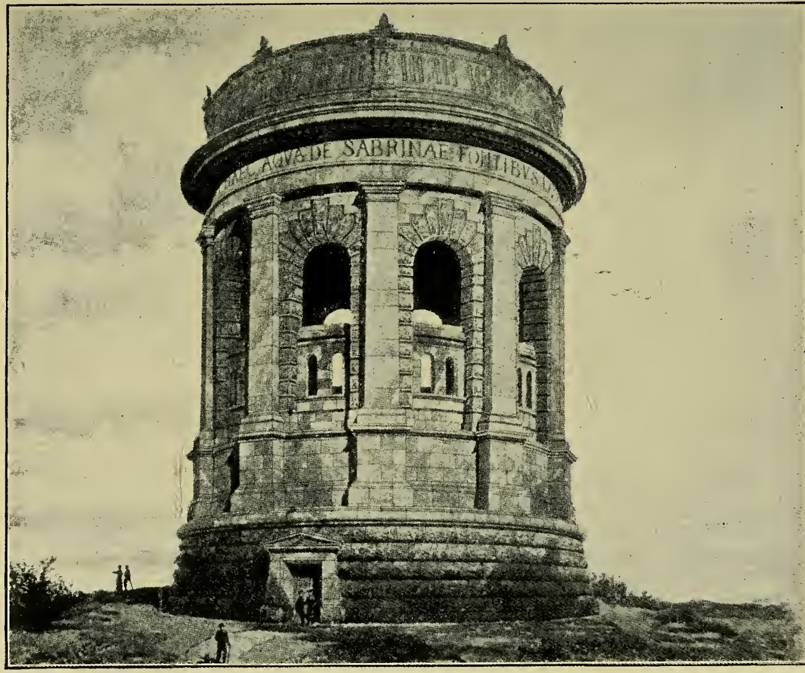
The pipes used in such works are manufactured with the greatest care, being cast vertically, socket downwards, so that the densest metal may be at the spot where there is greatest danger of fracture. Each pipe is then tested internally with coal-tar oil to an internal pressure of 45 lbs. per square inch in excess of the possible maximum exerted by the water, weighed, and its date, number, diameter, length, and thickness entered in a book; after which it is heated in a stove and dipped in a special anti-corrosive composition. During the laying of the line the position of every pipe is registered, together with the name of the man who laid it, and the date at which it is laid. The joints are made by running in molten lead between the socket of one pipe and the spigot end of its neighbour—a process that is too familiar in most towns to need description.

The first contract for the work was let in 1885, and on October 13, 1894, the first Thirlmere water arrived in Manchester, the inhabitants of which town are now assured of a splendid supply for many years to come.

From Cumberland we turn our attention to the equally hilly district of North Central Wales, where are the head waters of the Vyrnwy, a tributary of the Severn. The valley through which the river flows was once the course of a glacier, that scraped deep channels in the rock and piled boulders and stones across the glen so as to create a natural dam, behind which a lake was formed. After many years this lake was filled in with alluvial deposit, which rose to a height of 40 to 50 feet above the rocky barrier.

Who would have thought, fifty years ago, that this natural dam would prove of the greatest utility to far-off Liverpool, situated on the edge of unlimited water and yet casting anxious eyes towards regions where there was water fit to drink? In an interesting report on the Liverpool water supply the Corporation engineer, Mr. J. Parry, tells us how in 1865 a scarcity of water during the summer and autumn produced disastrous results. "The consumption was restricted in every way; trade was impeded, sanitary requirements were neglected, public baths and wash-houses were closed, and the death-rate from diseases caused and aggravated by a deficiency of water became abnormally high. The Medical Officer of Health for the Borough, the late Dr. Trench, in evidence before a Committee of the House of Commons, stated that hundreds of lives would have been saved during that season if there had been an increased supply of water."

As a result, great works were commenced in 1868 at



From a photo lent by] [*J. Parry, Esq.*

The Norton Water Tower on the Vyrnwy-Liverpool Aqueduct.

It is 110 feet high and carries a bowl which holds 650,000 gallons—the largest bowl in the world (p. 71).

[*To face p.* 66.

Rivington, in the Yarrow valley, where there are now eight reservoirs of 598 acres surface and a capacity of over 4000 million gallons, connected with Liverpool by a pipe line 15⅝ miles long, terminating at the Prescot Reservoirs. These works cost the Corporation 1½ million pounds.

But they did not suffice; and in 1878 Mr. G. F. Deacon, M.I.C.E., was instructed to survey the Vyrnwy valley and prepare Parliamentary plans, in conjunction with Mr. Thomas Hawksley, for the creation of a second supply.

The necessary Act received the royal assent in 1880.

As no lake existed from which to draw, the engineers decided to create one by closing the valley with a dam superimposed on the rocky ledge left by glacial action. The dam, which rises 85 feet above the river-bed, is 1172 feet long, 161 feet high (maximum), 127 feet thick at the base (maximum), and contains 260,000 cubic yards of masonry, weighing 510,000 tons. "Below the sill of the dam and above the outlet to the aqueduct, Lake Vyrnwy contains 12,131 million gallons. Its area is 1121 acres. In a single foot of depth immediately below the overflow, the lake contains about 304 million gallons; 5 feet lower a foot of depth contains 292 million gallons. . . . The average cross-section of this remarkable sheet of water does not differ widely from a horizontal base 2000 feet wide, with a depth of water over it of 70 feet, and end slopes 2¼ to 1."[1]

[1] Mr. G. F. Deacon. *Minutes of Proceedings of the Institution of Civil Engineers.*

This lake covers the site of the village of Llanwddn, with its forty cottages, church, school, and three chapels. By way of compensation, a new village, church and churchyard were built below the dam, and thither were removed the living and the dead.

The living have gained rather than lost by the move; new and better houses to live in, a well-regulated river, no longer subject to sudden spates, flowing past their doors, a fine carriage-way across the valley over the dam, and finally the dam itself, a noble and imposing structure on which the eye may rest with admiration, especially at times when the water passing over the top in an unbroken sheet 700 feet wide, thunders down on to the masonry below.

Except for the stone and sand all the materials used in the Vyrnwy dam—such as cement, bricks, timber, iron, machinery, plant, coal, &c.—had to be carted over ten miles of hilly country from the nearest Cambrian railway station of Llanfyllin.

The masonry throughout was executed with the most scrupulous care, since the sudden breaking loose of such a body of water as Lake Vyrnwy into the valley of the Severn, with its large towns, would be terrible to contemplate.

A great trench was first dug across the valley down to hard, sound rock. Boulders ranging up to hundreds of tons in weight were met with and removed; all long slopes in the sound rock were cut into steps; and the whole surface was scrupulously cleaned with

wire brushes and high-pressure water jets, and coated with Portland cement mortar. The interior rubble-work of the dam consisted mainly of large stones 2 to 10 tons in weight, laid by cranes on to carefully levelled beds of cement mortar. As each stone was placed, a number of men beat upon its centre with wooden mallets until it had settled down well, and squeezed up some of the mortar between it and the next stones. The interstices were very carefully filled and rammed with different-sized tools—blunt-ended swords for the narrowest cracks—and the precaution taken of only half-filling the vertical spaces between the last layer of masonry at the end of each day's work. During the nights, Sundays and holidays, these half-filled cracks were crammed tight with bags to exclude rain, frost, and sunshine. By this means the perfect junction of the work was assured.

The facing stones—cut to rectangular form—were bedded in like manner, but the mortar not brought to the outer edge. Cracks 6 inches deep from the face at the bottom, and 3 inches at the top were left and filled in with iron plates until the mortar had set. The cracks were then caulked to within an inch of the face with special cement, very carefully rammed. The result is a face that will suffer a minimum of disturbance from the contractions and expansions of cold and heat.

The dam is pierced by two culverts carrying pipes for the discharge of the daily 10 million gallons and the monthly 160 million gallons of compensation water.

This discharge has entailed an expenditure of £300,000, and except in the Vyrnwy stream itself—where its importance is small—its effect is trifling, and a concession rather to official pressure than to public needs.

About three quarters of a mile from the south-east end of the lake there rises from the water an ornamental tower connected with the public road—constructed by the Corporation at considerable expense along the north-east side of the lake—by four masonry arches. This tower is 170 feet high, and stands out 60 feet above top-water level.

On the outside of the tower are two inlet valves, each made up of six 9-foot tubes superimposed vertically on one another, end to end. By means of internal guides and a system of catches, it is possible to separate any number of these pipes from the pipes below, so as to permit the inflow of the water at any one of six different levels. The lowest joint is connected by a U-shaped bend with a similar series of tubes, working on the same principle, in the interior of the tower. This enables the man in charge to draw water from the surface, where it is purest, and introduce it into the tower in a state of approximate quiescence. The floor of the interior is pierced by three vertical bell-mouths communicating with as many 46-inch pipes leading to the aqueduct, each of which can be closed by a throttle-valve. Over the bell-mouths are cylindrical strainers, 9 feet in diameter and 25 feet high, of very fine copper gauze. As soon

as a strainer shows signs of fouling it is raised by hydraulic pressure, and cleansed by a washing turbine that removes all clogging matter from the gauze in a few minutes.

A concrete culvert, 730 yards long, leads the strained water to a tunnel piercing the hill at the south-east side of the lake. This tunnel, 7 feet in diameter and 2¼ miles long, terminates in an open well, in which the inlets to the three pipe lines are fixed. Each line is, or will be, of such capacity as to pass 14,000,000 gallons daily.

The total length of the aqueduct, in which there is very little tunnelling, is 67 miles. It falls into seven main portions, each of which terminates towards Manchester in a "balancing reservoir" on the hydraulic gradient. At Norton, where the natural level is 110 feet below the gradient line, a fine red sandstone tower of that height was built, carrying in the top an enormous bowl 80 feet in diameter and 31 feet deep at the centre. The bowl is supported, at the circumference only, by steel rollers, which allow for expansive movements. Its capacity of 650,000 gallons renders it the largest bowl in the world.

At the river Weaver the aqueduct sinks into a channel dredged for it in the river-bed, and is held down by flanges engaging with stout piles.

Between Norton and the Prescot Reservoirs the engineers had their hardest work to do. For, in addition to crossing four railways, the aqueduct encounters four canals and the river Mersey. The

Manchester Ship Canal length was carried out during the construction of the canal by cut-and-cover work, a culvert 305 feet long being built with terminal shafts at each end of ample section for three lines of 36-inch steel pipes.

Scarcely has the aqueduct risen on the north side of the canal when it descends again for a long plunge under the Mersey. "In point of difficulty, this work proved to be the most important upon the whole aqueduct. It was the first tunnel ever constructed by means of a shield under a tidal or other river through entirely loose materials. A romantic and instructive account might well be written of the battles with the elements, of the repeated failures and successes, and of the hairbreadth escapes, with ultimate pronounced success, which attended this subterranean and subaqueous work."[1]

The tunnel was only 900 feet long and but 9 feet in internal diameter, yet its construction occupied forty-seven months, baffled two contractors, and had to be completed by the Corporation engineer, Mr. G. F. Deacon.

The Company had contemplated laying the pipes in the Mersey bed in the same way as had been done at the Weaver, but the Parliamentary Committee ordered a tunnel under the river. Owing to the loose and porous nature of the Mersey bed the engineers at first proposed a tunnel that should be 104 feet below the

[1] Mr. G. F. Deacon. *Proceedings of Inst. C.E.*

surface on the Cheshire, and 174 feet below on the Lancashire side. But the estimated cost was so heavy that they decided to drive a horizontal tunnel 50 feet below high-water mark. The first contractors in twenty months had sunk the shafts and driven the tunnel for 57 feet. They then ceased work. The second contractors drove and lined 182 feet from the Lancashire shaft, and then also relinquished the task. The great obstacle was the difficulty in keeping water off the working face. In sinking a vertical shaft under air pressure it is easy to prevent the water from passing under the edge of the shield, which is horizontal, and therefore acted upon by an external head of water at all points equally. But in the case of a tunnel, the shield is vertical, and the head increases towards the bottom of the face. So that, where a porous water-logged stratum is encountered, if the pressure inside the shield suffices to keep out the water from the lower portion of the face, it may overcome the water pressure of the upper portion and force the air out and upwards. If, on the other hand, the upper portion only is considered, the pressure may not be great enough to exclude leakage into the lower part of the face. Matters were further complicated in the Mersey aqueduct tunnel by the head of water in the stratum varying with the tides.

The shield employed by the second contractors was too light for the work, and the cutting-edge collapsed for one-fourth of its circumference. When Mr. Deacon took over the responsibility, he had first to

repair the shield, a matter of great difficulty. But when the process was completed, operations progressed at a satisfactory rate, except during twelve days consumed in further repairs. At the end of four and a half months the tunnel was completed, the lining of cast-iron segments being placed in position behind the shield as the latter advanced.

The aqueduct is furnished with stop-valves every 2½ miles, and with 11 automatic valves, similar to those of the Thirlmere aqueduct, to shut in case of a burst.

In 1893 a telephone system was installed between Prescot and Vyrnwy, a double line for speaking, and a number of short lines from the automatic valves to the nearest signal station, so that an alarm will be given immediately after the occurrence of an accident.

On November 28, 1898, the outlet valves of the Vyrnwy Dam were closed, except those for compensation water, and by November 25 of the following year a new lake had been formed to the overflow level.

The quantity of water now delivered through the pipes (single line) from Oswestry to Prescot Reservoir is 15½ million gallons a day.

The Birmingham Scheme

The third aqueduct that we shall consider in some detail is one which in a few years will connect Birmingham with the head-waters of the Wye in two valleys of Radnorshire.

As at Manchester and Liverpool, the rapid increase of population has compelled the authorities to derive

an adequate water supply from a district favoured with a heavy and uncontaminated rainfall.

Mr. James Mansergh, called into consultation by the Corporation, laid his hand upon the little rivers Elan and Claerwen in distant Wales as the source from which the great hardware town should draw a copious supply.

The scheme for impounding these rivers in the same manner as the Vyrnwy was of course a very expensive one, but the common sense of the Birmingham ratepayers determined that the outlay must be faced, with the result that a Bill introduced by Mr. Chamberlain in 1892 received the prompt sanction of Parliament, granting the Corporation borrowing powers to the extent of £6,600,000.

At a spot half a mile below the junction of the valleys of the Elan and Claerwen, is reared a masonry dam 120 feet high and 600 feet long, which will pen in a serpentine reservoir extending a mile up the Claerwen and about two miles up the Elan valley. This reservoir is but one of six that will be eventually formed by as many dams, rising like a gigantic water ladder up the valleys. The total storage will be 18,000 million gallons, ensuring a maximum daily supply to Birmingham of 77 millions, in addition to 27 millions of compensation water to the Wye.

At present four dams are in progress; the lowest, the Caban Coch, referred to above; the next, the Careg Dhu, a submerged dam only a few feet high; the third, the Pen-y-Gareg, 128 feet high and 525

long ; the fourth, the Craig Goch, 120 feet high and 625 long. The first will impound 8000 million gallons, Pen-y-Gareg 1320 millions, the Craig Goch 2000 millions; the surface of each reservoir at highest level reaching to the foot of the dam further up the Elan valley. When a still larger quantity is needed two other dams will be built across the Claerwen, and their reservoirs connected with the main Caban Coch by a tunnel cut through the intervening hill.

When the dams are completed there will be seen a succession of beautiful lakes nestling between slopes well clad with woodland down to the water's edge.

The masonry is of the usual solid description prevailing in such works, the greatest breadth at the foundation being about equal to that of the maximum height.

For the accommodation of the workmen a regular village has been laid out on one side of the Elan, with streets of houses, a school, recreation rooms, a Corporation public-house, where limited quantities of liquor are sold at certain hours, and well-ordered hospitals. A bridge over the river is the only approach, and every one who would enter the village to seek employment is examined as to his physical condition, health, and capacities, before he is allowed to cross. A sort of *octroi* is established at the bridge end to keep out contraband articles, among which liquor is chief. Thanks to these arrangements the health and well-being of the community has been maintained at a high level, and the precedent is one which may with great advantage be followed.

The intake to the aqueduct is immediately above the Careg Dhu, the submerged dam, surmounted by a lofty aqueduct. The top water of the Caban Reservoir being 822 feet above sea level, and the crest of the submerged dam 780 feet, a slice of water 42 feet thick can be withdrawn before the levels on the two sides of the dam begin to differ. This slice will contain sufficient water for the daily compensation and a 27-million-gallon daily Birmingham supply for 100 days, with the yield of the watershed; and, when it has been withdrawn, 100 days more compensation water will still remain in the part of the main reservoir below the submerged dam, while the water impounded by the latter and the two upper dams will still be available for the aqueduct.

This is 74 miles long, from the Elan to the Frankley Reservoirs, between which points there will be a fall of 170 feet, or an average hydraulic gradient of 1 in 4000. About one half will be tunnel and culvert work, the balance six lines of 42-inch iron and steel pipes for the syphons (the longest 17 miles), in which the greatest pressure will be about 250 lbs. to the square inch. The water-way in the tunnels and culverts is 8 feet 6 inches in breadth and height. The longest tunnels are 4¼, 2½, and 1¼ miles in length. Wherever a river is encountered the pipes will cross on specially built bridges.

So in a year or two water will flow copiously from the wide glen in which the river rushes busily over its rocky bed on the way to the broad Severn. Cwn

Elan, at one time the residence of the poet Shelley, will share the fate of the village at Vyrnwy; and over the Caban Coch dam will roar, in flood-time, "the finest waterfall in the kingdom," to use the words of Mr. Mansergh, the engineer of the works.

Other Dams and Aqueducts

So numerous are these that reference cannot be made to all. But a few are specially worthy of mention. The Periyar Dam in Travancore, India, pens the river of that name into a lake of nearly 12 square miles area; and a tunnel through a hill on one side connects this reservoir with the Valgai River, which carries it down to the irrigation of Madura, a district that had for time immemorial suffered from severe droughts.

Two wooden-stave pipe lines join Denver City, Colorado, with a river 20 miles away in the Rocky Mountains. The lines are 30 and 34 inches in diameter, and pass 8,400,000 and 16,000,000 gallons daily. Six miles of wooden pipes, mostly 6 feet in diameter, supply Ogden, near Salt Lake City, with water from a storage reservoir containing 15,000 million gallons. These wooden pipes are said to be as durable as those of cast iron, provided that they are always full of water.

New York is fed by three aqueducts, the Old Croton, the New Croton, and the Bronx River; discharging respectively 95, 302, and 28 million gallons daily. The first is 41 miles long; the second 33¼ miles long, no less than 29¾ miles of which is in tunnel of 12¼-foot diameter. As the new aqueduct

approaches New York it makes a dive of 500 feet to pass the Harlem River. Its cost was £4,000,000.

Its feeder is a huge reservoir held up by the New Croton Dam—probably the finest extant example of such work—which has a maximum height of 290 feet, and a thickness at the base of over 200 feet.

There is probably no branch of engineering in which faulty design and workmanship can produce more disastrous results than that of dam-making. The sudden release of millions of cubic yards of water into a confined valley is attended with consequences that are truly awful.

In February 1852 the failure of a dam in Yorkshire swept away the town of Holmfirth. In 1895 the bursting of the Bouzey Dam, near Épinal, France, caused terrible loss of life.

But the most appalling instance of all is the memorable Johnstown disaster of 1889, which will probably have left a permanent mark on the reader's mind, even in these days of quick-crowding events.

By the courtesy of the proprietors of the *Wide World Magazine* the writer is permitted to append the following account of this catastrophe:—

"Johnstown is the county seat of Cambria County, Pennsylvania, and on the day of the disaster, May 31, 1889, the Conemaugh Valley, in which it is situated, had a population of about 30,000. . . . The town lies in a basin of the mountains, and is girt about by streams. On one side flows the Conemaugh River, on the other Stony Creek. The dam at the reservoir

of the South Fork Fishing and Hunting Club was improperly constructed. Originally built to create a reservoir for a feeder to the Pennsylvania Canal, it was abandoned when the canal became useless, and was then taken over by the club. The relief gates were permanently stopped up, and gravel, clay, and mud used to raise the embankment to a height far above that of the original structure.

"Observant men, some of them practical engineers, predicted a calamity, but no one could be induced to interfere. It is known that before the bursting of the dam those in charge of the reservoir foresaw the impending calamity, and tried to open a sluice-way on one side and so lessen the pressure. In spite of their efforts, however, the rising water reached the top of the dam, and on Friday afternoon, shortly after three o'clock, the overflow began, causing a break 300 feet wide. It took exactly one hour to empty the vast reservoir.

"Hardly had the warning rider reached Johnstown bridge before the great black wave of water, from 20 feet to 40 feet high, which at ever-increasing speed had rolled down the 14 miles from the reservoir, flung itself upon the doomed community, and almost swept it out of existence. Then followed a climax of appalling ruin—a scene which in its agony of death and destruction has never had its parallel in this Republic. With one great swoop over 3000 houses of brick and wood—stores, hotels, dwellings, factories—all were sent crashing and tumbling down the roaring torrent.

"The seething mass, speckled with human beings praying for life, was hurled against the great stone arches of the bridge. Above the roar of the flood, the crash of falling timber, and the swirl of the rushing water, were heard the cries of the dying, the wails of the mangled, and the agonised cries for help from strong men, fainting women, and helpless children. The force of the flood was such that it ground the wreckage into a compact mass, containing houses and parts of houses, furniture, waggons, cattle, the dead and dying—in short, a mass so dense that upon it rested, without sinking, the enormous weight of a full-sized locomotive. And yet, hardly had the wreckage begun to accumulate before fire broke out beneath the arches of the bridge, and stifling smoke and scorching flames rose above the scene of disaster and added terror upon terror.

"The total damage done by the rain-storm during the closing week of May was estimated at 50,000,000 dollars, the largest loss caused by any single calamity in the United States, excepting the Chicago fire. Up to the present 3000 bodies have been buried, and a fair estimate of the dead in the Conemaugh Valley is from 7000 to 10,000."

Thus Nature sometimes takes her revenge upon mankind for the fetters placed on her by the art of the engineer.

Note.—For the information contained in this chapter the author is much indebted to Mr. G. F. Deacon, M.I.C.E., and Mr. J. Perry Water Engineer of the Liverpool Corporation.

CHAPTER IV

THE FORTH BRIDGE

A GLANCE at the map of Scotland serves to show that that country is nearly cut in half, towards its southern end, by the Firths of Clyde and Forth running inland from the west and east respectively. They find their counterparts in the Severn and Thames estuaries, which, in a similar fashion, interrupt direct natural communication between the southern and midland portions of England. The interruption is, however, more serious in the Forth than in the Thames, inasmuch as the intervening water space is broader, and because South Fife and the Lothians are proportionately more important than Kent and Essex. In the case of the Thames, too, the estuary has narrowed into a river long before large towns are reached, and the crossing, even in its tidal parts, is a matter of small danger or difficulty.

Until recent years a traveller in the east of Scotland, when desiring to pass from Edinburgh to the counties of Fife and Perth, had to choose between an inconvenient and sometimes stormy passage of the Forth in a steamer at Queensferry, and making a long détour by rail round by Stirling. The loss of time entailed in either case was a serious handicap to traffic

From photos lent by] [*Sir Benjamin Baker.*

The Forth Bridge—the Largest Bridge in the World.

The upper view illustrates the method of construction—building out from both sides of the central towers simultaneously to maintain the balance of the whole. In the lower view is seen the completed structure, with its two main spans of 1,710 feet.

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between the counties north and south of the Forth; and at length it became so intolerable that schemes were propounded for connecting the banks of the Forth by a permanent means of inter-communication. As long ago as 1805 a proposal was brought forward to construct a double tunnel under the bed of the Forth; but matters got no further than the issue of a prospectus and pamphlet setting out the advantages of such a tunnel. Thirteen years later, one James Anderson, an engineer whose ideas and theories were on too large a scale for the engineering science of the time, suggested the erection of a bridge at Queensferry; the bridge to contain main spans of 1500 to 2000 feet, be 33 feet wide, and to cost the very modest sum of £205,000! The extant designs of the bridge make it clear that it was as well for any would-be shareholders that the scheme never passed beyond the paper stage.

When, however, in 1860, that greatest originator of vast engineering undertakings—the Railway—moved in the matter, things began to wear a more feasible aspect. The North British Railway planned a bridge about six miles north-west of South Queensferry, of 500-foot spans. But the project was dropped, to be revived in 1873, when the Forth Bridge Company was formed to carry out the designs of Sir Thomas Bouch for a suspension bridge with two large spans of 1600 feet each. The capital was actually subscribed, and an Act authorising the construction passed through Parliament. A commencement had

been made on the island of Inchgarvie in the foundation of one of the great main piers, 550 feet high, when work was suddenly stopped by the terrible disaster of the Tay Bridge in December 1879. Sir Thomas Bouch, as the engineer of that ill-fated structure, lost the confidence of the company and the public.

His designs were, therefore, laid aside, and investigations made into alternative methods of crossing the Forth. The committee of experts appointed to draw up a report abandoned, after due consideration, all ideas of driving a tunnel under the estuary, since the excavation necessary for the approaches on both sides would involve a very great outlay, and decided in favour of a bridge. In 1881 Messrs. Fowler and Baker (since honoured with a baronetcy and knighthood respectively) submitted plans for a cantilever bridge, of an altogether unprecedented size, to be constructed between North and South Queensferry.

Before going further into an account of this mammoth structure, it will be well to explain the principle of the cantilever.

An engineer, let us suppose, is called upon to bridge a gap of several hundred feet. How he will proceed to accomplish his task depends chiefly on the natural conditions of the locality where the bridge has to be made. If, for instance, there is dry land or shallow water on a hard bed below the gap, and the erpendicular height is not excessive, he may elect to build steel or brick piers a moderate distance apart,

and to lift on to the top of these girders of the truss type, each completed before being moved, and when placed in position independent of its neighbours, its weight being borne at either end by a pier.

But when conditions decree that the points of supports must be few and far apart, the difficulties of our engineer are much increased. In the case of the Britannia Bridge, Stephenson built huge tubular girders of 460 feet length, and hoisted them into position by means of hydraulic presses; but the difficulties to be overcome were enormous, and such a proceeding would be practically impossible with spans of 500 to 1000 feet. When such are required, the engineer resorts either to the suspension type of bridge (to be seen at Clifton, Hammersmith, Niagara, Brooklyn), or *builds out* from his supports on both sides simultaneously in such a manner that the structure as it proceeds is in a state of balance. The balanced arms may be rigidly joined to neighbouring arms in the middle of the span, and the connections over the piers severed so as to resolve the structure into a series of independent girders of the type first mentioned; or a gap may be left, and this be bridged over by an intermediate girder resting at each end on the arms. In this case the piers, or points of support, are the centres of pairs of *cantilevers*, as the balanced arms are named.

To make this quite plain, let us suppose two chairs to represent bases of two piers of a cantilever bridge. Men seated on the chairs are the towers. They

raise their arms simultaneously, maintaining their vertical balance. A very small pressure would depress their hands, so they are provided with sticks, which they grasp firmly at the upper end and rest against the seat of the chairs. A weight now hung from their hands is borne by the power of the sticks to resist compression, and the strength of the arms to resist extension.

Our men are two pairs of cantilevers. Between them is, let us say, an interval of two feet. This is bridged by a board of proper length resting on the upper extremities of the two inner sticks. If a third man sits on this "suspended girder," his weight causes his companions to lose their balance and fall inwards. So a couple of heavy weights are placed on the floor, immediately under the outer hands, and straps are passed from the anchorages over the hands.

The cantilevers can now withstand the weight on the central girder without losing their equilibrium. This explanation[1] made, we will return to the plans for the Forth Bridge.

On the north shore of the Forth, at North Queensferry, a somewhat triangular-shaped promontory projects southwards for a mile and a quarter into the water. At a distance of almost exactly a third of a mile south of the outermost point lies the small island of Inchgarvie, crowned by an ancient castle. Between Fife

[1] Adapted from an illustration given by Sir B. Baker in a lecture at the Royal Institution.

and Inchgarvie runs the main or north channel of the Forth, over 200 feet deep, and more generally used by shipping than the south channel, equally deep and wide, between Inchgarvie and the southern shore. There is on the south side of the south channel an expanse of shallow water 2000 feet wide.

The engineers erected three huge steel towers, each resting on four massive piers, on the extremity of the North Queensferry promontory, the western end of Inchgarvie, and in the shallow water at the south edge of the south channel. Each tower is 343 feet high from the piers to the summit of the steelwork, and a man standing on the latter would be 361 feet above high-water level. From these huge supports six cantilevers are built out, each 680 feet long. Those at the north and south ends rest on viaducts leading from the higher ground at a level of 157 feet above high water —the level of the permanent way. The other two pairs terminate while yet 350 feet apart, and these intervals are bridged by a couple of girders resting on the cantilever ends.

The bridge thus contains two enormous spans of 1710 feet each between the towers; the vastness of which will perhaps be better comprehended if we suppose one tower to be situated in the Strand opposite Chancery Lane, a second in the same thoroughfare at the Waterloo Bridge crossing, and the third on the Trafalgar Square side of St. Martin's Church. In height the towers would rival that of St. Paul's Cathedral.

On the north shore the bridge is approached by a viaduct 289 feet 11 inches long, and on the south by one of 1978 feet. The total length of the structure, including the length of the towers—145, 260, and 145 feet respectively—is 8295 feet 9½ inches.

The two main spans, crossing the two channels, permit the passage at all states of the tide of vessels whose topmasts are not more than 150 feet above high-water level, for a distance of 250 feet north and south of the central line of the spans.

The three central towers—to be referred to as the Fife, Inchgarvie, and South Queensferry—each rest on four solid piers of masonry built up from a firm foundation. Viewed sideways the four vertical columns composing a tower are parallel, but when seen from the railway track a decided taper is noticeable. The "batter" of 1 in 7½, which contracts the towers from 120 feet at bottom to 33 feet at top, is maintained throughout the structure to the cantilever ends, where the height has shrunk from 330 to 34 feet, and the width from 120 to 32 feet at the bottom.

Inchgarvie tower is longer than the other two—260 feet as against 145—for reasons that will be seen immediately. The sides of the towers are strengthened by huge tubular bracings which run from the foot of one column to the top of its neighbour; and all four columns are connected together horizontally, both top and bottom, by powerful ties. In addition to these are a number

of smaller bracings running in all directions, giving the whole structure wonderful stability.

Nature had favoured the engineers by placing Inchgarvie in mid channel, and providing firm matter on which to erect the piers. But, on the other hand, the Forth is exposed to gales, which on several days of the year blow with such fury as to prevent the passage of even paddle-steamers. The enormous pressure of a wind blowing upwards of 20 lbs. to the square foot on a structure of the size of the Forth Bridge had to be reckoned with. The tapering shape of the cantilevers towards their extremities had the effect of offering least surface to the wind where it had most leverage to twist the cantilevers about their supports; and the straddling of the columns further minimised danger from air pressure. But Messrs. Fowler & Baker thought it best to make a slight concession to the elements, by a contrivance that also provided for longitudinal expansion and contraction of the steelwork under varying temperatures.

Accordingly, one of the four columns in each tower was fixed rigidly to its pier. But the other three carried at their lower extremities bedplates moving over corresponding bedplates attached to the piers. Strong bolts passing up through slots in the upper plates allowed the latter to move slightly horizontally, some in a circular path round the fixed pier, and all in the direction of the centre line of the bridge. The two extreme cantilevers were so fixed at the viaduct

ends as to prevent side-play, but permit longitudinal expansion.

The Inchgarvie tower differs from the other two in having neither its north nor its south cantilever fixed, and both can therefore exert a twisting strain on the tower. Great care was necessary to make due provision for such movements in the attachment of the suspended girders in the middle of the two main spans. They are hung in such a manner from the cantilevers that longitudinal expansion is possible in both girders at their Inchgarvie ends through the medium of sliding blocks; while rocking-posts, or pivots, are provided at both ends to enable them to adapt themselves to any lateral sway of the cantilevers.

Inchgarvie tower, on account of its "splendid isolation," is also at a disadvantage with regard to "live," or train, loads. If two heavily-laden trains pass one another at the end of a cantilever they exert a great pull on the central tower, tending to lift it from its further piers. In the case of the Fife and Queensferry towers such a loss of balance is obviated by terminating the landward cantilevers in huge boxes, each containing 1000 tons of iron, and resting on the end viaduct piers. Such a provision was impossible for Inchgarvie, so the engineers increased its length by 115 feet, to give the columns further from the live weight a greater counteracting leverage.

It is interesting to notice as an example of the thoroughness with which all the work on the Forth

Bridge was carried out that, as a preliminary operation, three wind gauges were erected in the summer of 1882 on the top of the old castle on Inchgarvie, and daily records taken. Two of these were fixed to face east and west, from which directions the wind would strike the bridge almost at right angles to its longitudinal axis. The third revolved, to meet winds blowing from all quarters. The largest wind-board, 15 by 20 feet, or 300 square feet in area, had cut in it two circular openings of $1\frac{1}{2}$ square feet area, the one at the exact centre and the other in the right hand top corner, each containing circular plates registering pressure independently of the rest of the board. The fact that on March 31, 1886, the upper opening recorded only 22 lbs. per square foot, while the centre pressure rose as high as $28\frac{1}{2}$ lbs., seems to show that great wind pressures are very unevenly distributed over a large surface. This is confirmed by the records of two additional revolving gauges set up on the central towers, where simultaneous pressures varied as much as 10 and 12 lbs. between the different piers.

The first thing to be done in the actual work of construction was to accurately fix the positions of the main circular piers. Direct measurements with tape and chain being impossible, the surveyors had recourse to triangulation. A base line, 4000 feet long, was laid on the south shore; an observatory built; three points taken on the centre line of the bridge; and twenty other stations laid down as required.

Careful trigonometrical calculations were made; but, in order that there should be a minimum of error with regard to the distances apart of the three principal stations on the centre line, the measurement of the north span of 1700 feet from the centre of the north circular pier on Inchgarvie to the south circular piers on Fife was checked in the following manner, as described by Mr. Westhofen in his account of the Forth Bridge:—[1]

"In a straight portion of the North British Railway a distance of 1700 feet had been carefully measured and marked and transferred to high posts at the side of the cutting. Upon these posts notched knife-edges were placed at the two extremities. A fine steel wire, about $\frac{1}{20}$ of an inch in thickness, was laid along the span and drawn over the knife edges, with a certain amount of stress put upon it, previously agreed upon. Thus drawn up, the wire left a certain amount of sag in the centre, which was carefully measured by level and noted. Two narrow copper tags were then soldered on to mark the end points. The wire was then coiled up and kept ready for use. The temperature was noted. On the two shores, immediately under the piers which marked the stations, places had been prepared for levels, by means of which the amount of sag in the wire could be fixed. On a calm, cloudy day, with the temperature about the same, the wire was taken across the north channel

[1] To which account the author is greatly indebted for his information.

and laid down upon the prepared knife-edges on the piers, and with the same amount of sag allowed, the two copper tags soldered on should have coincided with the notches in the knife-edges, provided the distance was correct."

The results showed a discrepancy; but, after the main spans were completed and measurements taken along the girder, the difference was reduced to but 1 inch in the north span and 6 inches in the south.

The amount of preparatory work to be done before building operations got into full swing was on a scale proportionate to that of the bridge itself. On the south shore the high ground was cut into terraces, and on these were erected a shop for fitting the tubular parts of the bridge; another for the lattice-work; a drill road; a carpenters' shop; a pattern shed; and a drawing-loft, 200 feet by 60, in which, on a blackened floor, full-sized drawings and templates of various parts of the superstructure were made. By the edge of the water a sawmill was established. Houses for accommodating a small army of workmen had also to be built, and a water-supply provided. Special services of trains and steamers were organised. An efficient system of handling, storing, and transporting materials for 140,000 cubic yards of masonry and 55,000 tons of steel, besides an equal weight of temporary appliances was devised. A cable for telephonic communication between the various shops and offices at working centres crossed the bed of the Forth. And we may close a very incomplete list by

naming the construction of a jetty 50 feet wide and 2100 feet long, extending from the South Queensferry shore to the piers of the Queensferry tower. This jetty was a considerable piece of engineering in itself. It carried lines of rails for conveying stores and steelwork to the Queensferry piers, or to barges plying between it and Inchgarvie and Fife.

Ten out of the twelve circular piers, carrying the three towers, were constructed by means of caissons or coffer-dams. These may be described as contrivances for laying dry a space below water-level, or preventing a free flow of water over it. In soft ground a coffer-dam is formed by driving down two circles of long contiguous piles, leaving between the circles a space of a few feet, which is filled in with water-tight clay-puddle. The dam thus formed is provided with sluice gates to let in the water when required. In some cases the water is excluded until half-tide, when the rising pressure may make it expedient to admit water, so as to equalise the pressure on both sides of the dam. When the dam is strong enough to resist high-water pressure, it is called a whole-tide dam, and the space inside can be worked upon continuously.

On rock, recourse is had to steel-sided caissons, the sides being cut to fit the contour of the rock on which they rest, and their bottom edges made water-tight by means to be presently described.

In deep water, where outside pressure becomes very severe, an ingenious structure called a pneumatic

caisson is used. This consists of an upright circular iron cylinder, resembling a gasometer in outline, built of stout plates closely riveted together. Six or seven feet from the bottom a watertight metal diaphragm, or floor, shuts out the lower part of the caisson from the upper air, and so gives it, when the whole is sunk, the properties of an ordinary diving-bell.

Leaving for a moment a further description of the caissons, let us turn our attention to the following table, showing the depth of the deepest points of the twelve piers of the Forth Bridge towers below high water :—

Fife . . .	N.W.,	7 ft. below high water.
"	N.E.,	7 " " "
"	S.W.,	25 " " "
"	S.E.,	37 " " "
Inchgarvie	N.W.,	23 " " "
"	N.E.,	26 " " "
"	S.W.,	72 ft. 1 in. below high water.
"	S.E.,	63 " 9 " " "
Queensferry	N.W.,	85 " below high water.
"	N.E.,	89 " " "
"	S.W.,	71 " " "
"	S.E.,	73 " " "

As each of the piers rises 18 feet above high water, the total height of the structure at the north-east of Queensferry tower is 330+89+18=437 feet!

No dams were required for the Fife north piers. The Fife south piers were built inside steel and wooden pile coffer-dams. In the case of the Inchgarvie north piers, stagings were erected over the

sites of the piers and soundings taken at intervals of 6 inches round the circumference of a 60-foot circle. An iron belt 3 feet deep and 60 feet in diameter was then constructed, and to this were attached vertical steel plates of a length corresponding with the depth of water immediately beneath. As soon as the whole had been completed, the shell was lowered into place, the uppermost part resting in a groove cut in the higher levels of the rock. Rows of concrete bags were then placed outside, and clay rammed between them and the plates until tight joints permitted the pumping out of water at half tide, an operation entailing the removal of 590,000 gallons in less than an hour's time.

From a reader's point of view the remaining six caissons — the southern Inchgarvie and all four Queensferry—working on the pneumatic principle, will be of especial interest, and as such merit a more detailed description.

The pneumatic caissons, 70 feet in diameter at the bottom, and of different heights, were erected on the South Queensferry shore; and when complete were loaded with concrete and tools, and launched, to be towed to their final resting-places. These last had already been carefully surveyed by means of a circular raft of planking and timber balks, 70 feet across, having a central upright staff, and a carriage running on a circular rail laid a foot from the outer edge. Attached to the carriage was a drum of steel wire, raising and lowering a 60 lb. weight for taking

soundings. The raft was moored in such a position that its central staff occupied a certain point, determined by instruments, and soundings were made. At South Inchgarvie, where the foundation is sloping rock, piles of sandbags were arranged at the points of greatest depth, so that the caissons should settle on an even keel. These caissons, after being towed into position, were gradually loaded with deposits of concrete until they began to touch ground at low water. Additional piles of sandbags were then placed below in the air-chamber, and the rock was gradually cut away on the high side to make a chase for the caisson to rest upon when loaded sufficiently to lose all its buoyancy at high water. The circular area of bed-rock and the supports were then removed by degrees.

Let us imagine ourselves furnished with the engineers' permission to visit the "working face" below a caisson. On reaching the deck of the caisson we see a powerful steam crane raising loads of débris out of an air-lock, at the upper end of a tube communicating with the air-chamber 60 feet below. We are ushered into the workmen's air-lock, a circular chamber with another circular chamber 3 feet 6 inches diameter in its centre. The doors through which we entered are then closed tight, and a tap communicating with the air-chamber opened until the pressure has gradually risen sufficiently to allow the opening of doors in the central tube. We descend ladders, experiencing a sensation

of great oppression on the ears and eyes, and presently find ourselves among the workmen—mostly North Italians, with a sprinkling of Germans, Belgians, French, and Austrians, who have been brought over by M. Coiseau, the contractor, for this part of the work, not as being better physically able to work under such circumstances than Britons, but as more experienced. Powerful electric lights of 200 candle-power illumine the chamber, the sides of which slope outwards towards the bottom, ending in a stout steel cutting-edge. Two men, armed with heavy sledge-hammers, are beating on the top of a crowbar held by a third; they are drilling or "jumping" holes for blasting charges. As soon as enough are made the charges will be inserted and, when every one has withdrawn, after carefully shielding the lamps, be fired from above by electricity. Then the men will descend again and remove the débris by means of the skips that pass up and down their own air-lock and well. Under one side of the caisson, where piers of concrete bags support the edge, men are thrusting out sandbags that have served their purpose; and in the gaps we may perhaps see the startled visages of salmon, dogfish, and other denizens of the deep that from time to time are attracted to the glare of the lights within.

In the Queensferry caissons a somewhat different spectacle would present itself. The drills and cement piers are absent; there is no preparation for blasting, for we stand now on more or less stubborn clay. If

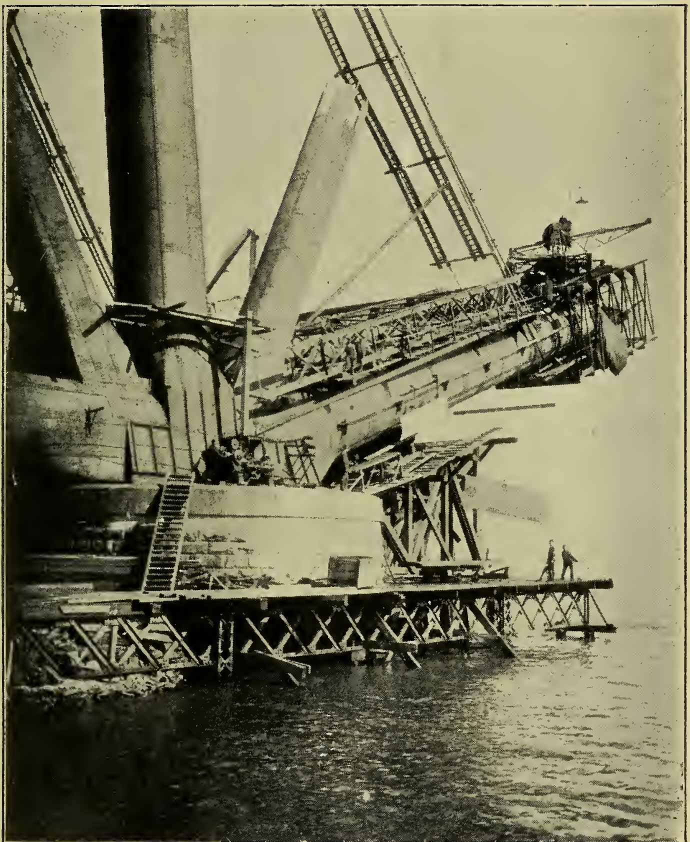
the sinking of the caisson is still in its earlier stages, we make the acquaintance of the air-ejector for discharging the silt that mixes readily with water. A man standing in the muddy mixture lowers to its surface the nozzle of a hose, and another man turns on a large tap that controls the passage of the compressed air of the chamber to the outer atmosphere. As soon as the tap is opened a rush of air takes place, and the nozzle being dipped into the liquid some of the latter is carried up the hose by the momentum of the air and shot out at the farther end of the piping in intermittent spurts. The rate of ejection depends largely on the skill of the operator.

On reaching the hard and stubborn clay below the silt, the workmen's energies become unequal to the task of removing the "spoil" by mere muscular effort. The forces of nature are now called in. An hydraulic spade, the invention of Mr. Arrol, is set up. A word about this spade. It is, described briefly, an hydraulic ram working at a pressure of 1000 lbs. per square inch. To its lower end is attached a large spade, and to its top a headpiece. Two men fix it vertically, with its head against the roof of the chamber, and another turns on the water, which with giant strength forces the spade into the boulder clay, detaching a slice 16 to 18 inches deep and 4 inches thick. The spade is then moved on a little, and the operation repeated until trenches have been cut all over the bottom.

The air-pressure under which the excavators had

to work rose on occasions as high as 40 lbs. to the square inch, yet not a single death can be directly attributed to these abnormal conditions. "The principal bad effect produced by the air-pressure," says Mr. Westhofen, "appears to be that of severe pains in the joints and muscles of the arms and legs. As these have been in most cases traced to hard work and copious perspiration, and also to too long a stay under pressure, it has been suggested as a probable cause that small globules of air make their way through the skin, or between the skins, where they remain and, on the workmen returning to ordinary atmospheric pressure, expand, and thereby cause the most agonising pains in the joints, the elbows, shoulders, knee-caps, and other places. In seeming confirmation of this the sufferers got instant relief on returning to high pressure. Thus it happened that many of those afflicted with this disorder spent the greater part of Saturday afternoon and Sunday under air-pressure, and only came out when absolutely obliged to do so. Various researches were made by members of the medical staff in the endeavour to give relief or obtain a cure, but, so far, not with any degree of success."

Owing to the nature of the river bottom the sinking of the Queensferry caissons was a matter of much anxiety to the engineers. At low water especially, when the cutting-edge bore down with greatest force, a sudden settlement was to be feared, and therefore the men were then generally withdrawn; a precau-



From a photo lent by] [*Sir Benjamin Baker.*

The Fife Cantilever, Forth Bridge.

This illustration gives a good idea of the complex steelwork at the meeting-places of the chief members of this bridge. The horizontal tube over the pier, to which the tower column and diagonal support, besides the strut and bottom member of the cantilever, are fastened, is called a "skewback." To the extreme right are seen a rivetting cage and a crane, which move forward with the extension of the cantilever.

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tion that on one occasion at least was amply justified, for the caisson without warning sank 7 feet, filling not only the air-chamber but also part of the air-lock shaft with mud and silt.

The most serious accident that took place during the building of the bridge happened to the north-west caisson of Queensferry. It had been towed into position during high tide, and at the ebb took the ground so firmly that, an unusually high tide occurring soon afterwards, it filled and canted over. The consequent pumping operations were conducted too fast, and before the caisson could be sufficiently strengthened on the inside the water outside burst in the plates, making a rent about 30 feet long on the lower side This unfortunate occurrence necessitated the construction of a heavy timber frame round the caisson, and nearly ten months passed before it was afloat again.

As soon as the caissons had reached their full depth, all tools and appliances were removed from the air-chamber, and this last filled up with concrete shot down the shafts. Then the caisson above the chamber was filled to low-water level, where the granite courses commenced, having at this point a diameter of 55 feet. At 18 feet above high-water level the piers terminate, and are carefully levelled to receive the lower bed-plates, which are securely held down by bolts built into the masonry.

The piers being ready, the erection of the steel superstructure commenced in the fixing of the "skew

backs" or great steel tubes, with one side flattened and attached to the upper bed-plates. From the skewbacks run out the lower members of the cantilevers, the columns of the towers, the huge diagonal struts uniting the foot of one column with the top of its neighbour, and horizontal girders towards the other piers.

As soon as the horizontal work immediately above the piers was finished, the vertical columns were taken in hand. Huge plates, already correctly drilled and shaped, 16 feet long and ½-inch thick, were placed in position by means of cranes. When columns and struts had reached a point 50 feet above the piers, stagings were built on girders 190 feet long in the Fife and Queensferry towers, and 350 feet at Inchgarvie, these girders resting in turn upon very strong box girders stretching east and west from column to column, and raised at each end by powerful jacks situated in the columns themselves. In this manner the need for continuous scaffolding was obviated, and a riveting cage, consisting of a riveting machine enclosed in a cylinder of stout iron wire to prevent loose rivets, tools, &c., from falling with disastrous effects on the workers below, followed the stagings up the columns, making permanently secure all the work bolted in position by the men above.

The pressure on the rams required to lift the stagings—which at Inchgarvie weighed 700 tons—was 3920 lbs. to the square inch. We read that the first lift of the Inchgarvie platform occupied eighteen days,

whereas the last, owing to the increased skill of the men, took but five hours !

Great care was necessary in the erection of the towers to ensure that their lateral "batter" and centre lines should be absolutely correct. From time to time the structure was checked by means of theodolites, and when any deviation from accuracy had been observed, hydraulic rams were applied to force the tubes into their proper position. Any one who has tried to bend or straighten the small tubes of a bicycle will have some faint idea of the power needed to master these giant 12-foot cylinders.

On the completion of the towers the lower and upper members of the cantilevers were commenced. The upper members, being in tension, are all straight and of lattice-girder work; but the lower, or compression members, are of tubular construction, and spring outwards in an arch of polygonal outline, as it was found inexpedient to curve the tubes. The tubes shrink in diameter and thickness as they leave the towers, and approach laterally to the corresponding tubes of the nearly parallel member on the other side of the cantilever. So that at its end the cantilever has diminished in breadth from 120 to 34 feet, thereby gaining greatly in power to withstand wind pressure.

Both top and bottom members were built out by the help of travelling cranes, which, starting at the foot and summit of the columns, raised material from barges in the river below, placed it in position, and then moved forward. On reaching the ends of the

cantilevers they climbed the upper bow-shaped surface of the suspended girders. These were built out from their ends in a manner similar to that of the cantilevers, and a junction was effected near their centres as soon as the temperature of the atmosphere had expanded the steelwork of the whole structure sufficiently to bring the final bolt holes opposite one another. The falsework connecting the girders to the cantilevers was then cut, and the girders rode free in their slides and rocking-posts. In the case of the north central girder an interesting episode took place. The junction had been made, and the men were cutting the rivets of the falsework, when suddenly the remaining rivets, some thirty-six in number, were shorn by the contraction of the structure, and the plate ties parted with a noise like that of a large gun, shaking the bridge slightly from end to end. The incident caused a little temporary alarm, and lost none of its importance as reported in the papers, but so far from being a mishap was merely an instance of Nature saving Man a considerable amount of toil.

The permanent way was laid on the internal viaduct traversing the Bridge from end to end. Four parallel rail troughs, 18 inches deep and 16 wide, were filled for 6 inches with teak and pine blocks, and on these the platelayers placed longitudinal teak sleepers, securely bolted down at intervals to the blocks. The rails, of "bridge" section, are exceedingly heavy, weighing 120 lbs. per lineal yard. At the sliding ends of the central girders, where there is allowance made

for a longitudinal expansion of 2 feet, special ingenious joints are provided, which enable the rails to slide backwards and forwards without losing their gauge. On each side of the track is a 4-foot path for the exclusive use of the officials of the line employed in looking after the bridge.

Before closing this chapter, which, for want of space, has not dealt with many interesting points of construction, we may notice some statistics which will escape the charge of dryness in that they help the reader the better to appreciate the nature of the undertaking. Work on the Bridge began in January 1883. On March 4, 1890, the (then) Prince of Wales formally declared the Bridge open to traffic, in a severe windstorm that impressed the company present by its impotence to shake the mighty framework of steel. The seven years of work represented an expenditure in materials and labour of £3,177,286, the largest half-yearly payment being made in the last six months of 1887, when £253,500 were disbursed.

The piers carry a total weight of 50,958 tons of steel. Of this Inchgarvie Tower alone weighs 7036 tons, or nearly as much as the Eiffel Tower, which could be laid comfortably in either of the two main spans; and a column twice as high as St. Paul's laid at its end would barely fill the gap remaining. To sever the top ties of the towers a strain of 45,000 tons would be required; and Sir Benjamin Baker himself assured his audience at a lecture that half-a-dozen of our weightiest ironclads could be safely suspended from

the cantilever ends, so far as the Bridge was concerned.

The total number of rivets is at least 6,500,000. Allowing an average length of 2 inches a rivet, they represent a bar 200 miles long, varying in diameter from $1\frac{1}{8}$ inch to $\frac{1}{2}$ inch.

As many as 4600 workmen were engaged on the Bridge during the busiest times. Among these accidents were frequent, but mainly attributable to the indifference and carelessness of the men themselves, who, in spite of repeated ocular proofs to the contrary, appeared to think that the fall of a carelessly thrown chisel or other tool would not be attended with disastrous results. We are not therefore surprised to learn that in six and a half years no less than 57 fatal, and 106 very serious accidents occurred, and it comes as a curious reminder of the unreasonableness of workmen to read that the principal strike was brought about by the fall of a riveting stage, which collapsed because those responsible for its management neglected ordinary precautions while hoisting it.

Nothing that can be said will probably more vividly present to the reader the size of the Bridge than the statement that the area to be painted once every three years, inside and outside, is 145 acres, or that of a good-sized farm. The whole of the outer surface was covered *five times* during construction, once with boiled linseed oil, twice with red lead, and twice with oxide of iron paint. A large staff of men is always

at work putting on fresh coatings to withstand the corroding action of the salt sea breezes.

The railway passenger is in a particularly unfavourable position to view the Bridge as he passes. By putting out his head he can only see a long vista of huge tubes and girders, foreshortened in such a way as to lose their full impressiveness. Moreover, he is at an elevation near the centre of the total height. To get a just scenic idea one should approach the Bridge by boat on the Forth, so as to take it in flank. Then what a stupendous structure it is! a thing of huge lines and triangles; its geometrical repetitions out of keeping with the lovely landscape, and yet having a grandeur of their own. With what pride must the engineers have looked upon the finished structure, the child of their brains, remorseless consumer of steel and stone, reared amid the clash of monster machines, nursed by small armies of workmen! What were the eight years of battle with wind and wave, and their trials and struggles, now that the last rivet had been driven in, and the track opened for the iron steed—a mere fly among the steel web of the Bridge, yet the whole built for the passage of the fly! Surely the Forth Bridge is the incarnation of engineering romance, in which brain and metal and stone have joined hands with the powers of Nature to triumph over the obstacles placed in man's way by Nature herself.

Mr. Westhofen, the engineer in charge of Inchgarvie, has an eye for the picturesque; and the author

feels that he cannot do better than quote in conclusion his eloquent description of the view to be had *from* the Bridge.

"The view from the summit of the central tower on a clear day is magnificent. The broad river itself, with craft of all sorts and sizes, in steam or under sail running before the wind, cutting across the current on tack, or lazily drifting with the tide, is always a most impressive spectacle, upon which one can gaze for hours with an admiring and untiring eye. And such it is, whether viewed in the glory of sunrise or sunset, in broad daylight, with the cloud shadows flying over the surface, and a thousand ripples reflecting the sun's rays in every conceivable shade of colour, or in the soft haze of a moonlight night. The sunsets in summer are always magnificent, whether due to Krakatoan volcanic dust or to the vapours of the distant Atlantic, but there have also been many sunrises in early autumn when a hungry man could forget the hour of breakfast, and one could not find the heart to chide the worker who would lay down his tools to gaze into the bewildering masses of colour surrounding the rising light of day. An unbounded view more than 50 miles up and down river. . . . At night, too, a sight is presented not easily forgotten; the flashing lights of the May and of Inchkeith, and many others stationary, such as the harbour lights of Granton, Leith, Newhaven, and Burntisland, combine to form a beautiful picture. At times of continued east wind, when large and small craft run for

shelter into the Firth, it is not unusual to see from 150 to 200 vessels anchored in the roads, and the long straggling lines of their masthead lights give the appearance of a busy town of many streets having suddenly risen from the waters.

"On Jubilee night (21st June 1887), although the atmosphere was somewhat thick, sixty-eight bonfires could be counted at one time on the surrounding hills and isolated points, while the great masses of the central towers of the Bridge, lighted up by hundreds of arc-lights at various heights where work was carried on, formed, with their long-drawn reflections in the waters of the Firth, three pillars of fire, and afforded a truly wonderful and unique spectacle."

CHAPTER V

THE TOWER BRIDGE

LESS imposing as a structure than the giant conqueror of the Forth is the new bridge that spans the Thames, a short distance east of the Tower of London, from which it derives its name.

The Tower Bridge is, however, of such importance and interest, both on account of the problems that it has solved, and from the manner in which it has solved them, that this great framework of metal and masonry, so familiar to the Londoner, deserves inclusion among the chief engineering feats of modern times.

The general outlines of the Bridge, being so well known, need little detailed description. Technically, it is a three-span bridge, the two outside spans of the suspension type carried on stout chains that pass at their landward ends over abutment towers of moderate height to anchorages in the shore, and at their river ends over very lofty towers, themselves connected at an elevation of 143 feet above high-water level. Extremely powerful ties, borne on the connecting girders, unite the two pairs of chains, making the suspension spans to support one another in a horizontal direction.

The central span has two footways and one roadway. The high-level girders bear the upper footway, reached by two hydraulic lifts situated in each of the main towers.

The most notable feature of the Bridge, unless we except the unique combination of steel and masonry work in the towers, is the method of enabling traffic, pedestrian and vehicular, to cross the 200-foot space between the towers, at the level of the roadway of the two outer spans.

History repeats itself in engineering as elsewhere, and, as an example, we see here a reversion to the idea of the drawbridge that shut off the mediæval fortress or town from the hostility of the outside world. Principle apart, however, it is a far cry from the wooden platform, heaved laboriously aloft by creaking chains, to the massive 1200-ton steel leaf raised noiselessly by the unseen energy of hydraulic engines.

Before entering into details of construction, it will be interesting to glance for a moment at the antecedents of this latest-born of Thames bridges—the reason for its erection, and the considerations that cast it into its present form.

Let the reader take a map of London and fix his eye on Blackfriars Bridge. A line drawn due north and south through the bridge would approximately bisect the metropolis. A steamboat travelling westwards from this point passes in succession under Waterloo, Westminster, Lambeth, Vauxhall, Chelsea,

Albert, Battersea, Wandsworth, and Putney Bridges — nine in all — open to vehicular traffic. On an eastward journey of equal length it would, however, have to lower its funnel for but two—the Southwark and London—assuming the Tower Bridge to be still in the future. Yet both banks are thronged by some of the most densely-populated districts of London, so near each other and yet so far for want of means of communication.

A further reference to the map shows us why things should be so. This is a region of docks and wharves, the latter reaching up to London Bridge, from which we have often watched the unloading of cargoes.

The engineer, called in to effect a compromise between the crying needs of road traffic on the one hand and the equally important interests of river traffic on the other, is able to suggest several methods of cutting the Gordian knot:

1. A low-level bridge, with an opening for vessels through it.

2. A high-level bridge, with inclined road approaches.

3. A high-level bridge, with hydraulic lifts at each end.

4. A tunnel under the river, with inclined approaches.

5. A tunnel with hydraulic lifts at each end.

6. A ferry.

Of these the first would be most convenient for the landsman, but most inconvenient for the sailor. The

second and fourth necessitate very costly approaches, the third and fifth continual blocks in the traffic; and as regards ferries, they are at best but very poor substitutes for a bridge.

Among the many plans submitted since 1867 for a bridge, one is particularly noticeable for its originality —that of Mr. C. Barclay Bruce. He proposed a rolling bridge, to consist of a platform 300 feet long and 100 wide, which should be propelled from shore to shore over rollers placed at the top of a series of piers 100 feet apart. The platform would have a bearing at two points at least, and, according to the designer's calculations, make the journey in three minutes, with a freight of 100 vehicles and 1400 passengers. Another engineer, Mr. F. T. Palmer, proposed a bridge which widened out into a circular form near each shore, enclosing a space into which a vessel might pass by the removal of one side on rollers while traffic continued on the other side. As soon as the vessel had entered the enclosure the sliding platform would be closed again, and that on the other side be opened in turn.

In 1878 Sir Joseph Bazalgette, engineer to the Metropolitan Board of Works, recommended the construction of a bridge that should give a clear headway of 65 feet above Trinity high-water level, but a Bill brought into Parliament for power to build it was thrown out on the ground that the headway would be insufficient, and on account of the awkward special approaches.

To avoid wearying the reader with a list of projects we will pass straight on to that of Mr. Horace Jones, the late City architect, who in 1878 was asked to report upon the various projects of Sir Joseph Bazalgette and make suggestions on his own account. He maintained that, as a high-level bridge would not give satisfaction, a structure of the same level as London Bridge, opening at the centre by means of hinged platforms, or bascules, might be advantageously employed. From his design has sprung that of the Tower Bridge—the joint work of him and Sir J. Wolfe Barry—which provides a central opening of 200 feet clear and a headway of 135 feet. An Act for its construction having been passed in the autumn of 1885, contracts were let for the foundations of the piers and abutment towers up to the level of 4 feet above high-water mark. On June 21, 1886, the (then) Prince of Wales laid the foundation stone.

The masonry piers on which the main towers stand are remarkable for their size—100 feet wide by 205 long—which exceeds that of any in the world, with the exception of those of the Brooklyn Bridge. The piers being but 200 feet apart, the engineers, who were under agreement to leave a clear way of 160 feet between them, could not build both simultaneously as a whole, since the scaffoldings would have narrowed the opening beyond legal limits. They therefore adopted a system of small caissons, which should be sunk so as to form a broad wall round the area of the pier, and enclose a space of

34 by 124½ feet, to be dealt with as soon as the exterior caissons were in position.

On the north and south sides of each pier four caissons were sunk, 28 feet square and 2½ feet apart, each end of the rows being joined by a triangular caisson. While one pier was in course of construction, the shoreward row of caissons for the other pier was also sunk, thus saving time without obstructing the river.

Reference has been made in the previous chapter to the sinking of caissons; so it need here only be stated that at the Tower Bridge no pneumatic caissons were employed, but only the open variety. Divers cleared away the gravel and mud until a caisson had descended such a distance into the stiff London clay at which it was thought safe to pump out the water at low tide, and then navvies were turned in with pick and shovel. At a depth of 19 feet the caissons were undercut, *i.e.* the workers burrowed beneath their lower edges into the clay for a distance of 5 feet horizontally, and 7 feet vertically. The undercutting proceeded in sections—filled with concrete in succession—so that the caisson should not be left unsupported. When all the ten external caissons had been sunk and filled in, the narrow spaces between them were also filled, and the interior enclosure pumped dry and excavated. Finally, there emerged from the water a couple of gigantic piers of concrete, granite, and bricks, able to withstand without settlement a load of 70,000 tons. Their cost was £111,122.

The contract for the steelwork in the superstructure was let to Sir William Arrol & Co., of Glasgow, who, as the reader will remember, had already taken an important part in the construction of the Forth Bridge.

Before any metal-work could be placed in position, it was necessary to erect stagings from the shore abutments to the centre piers. This work occupied some months, and when it was completed operations at once commenced on the main towers.

Each tower consists of four octagonal columns, connected at a height of 60 feet above the piers by plate girders, 6 feet deep, across which are laid smaller girders to carry the first landing. Twenty-eight feet higher is the second landing, similarly constructed, and above that, at an equal distance, the third landing leading to the high-level footway. The columns each rested on massive granite slabs previously covered with three layers of specially prepared canvas to make the pressure even and the joint water-tight. They were keyed to the bed-stones by great bolts built into the piers.

The first length of column plates having being riveted in position by hydraulic riveters, the second length was added by means of a crane placed on the piers, and when the crane had been raised aloft on special trestles the third length followed. The first landing served as a platform from which to build upwards in like manner to the second, which in turn became the base of operations. All four columns in

each tower were braced diagonally to resist the wind pressure—calculated at a maximum of 56 lbs. to the square inch, or several times greater than has ever been registered in that locality.

The columns finished, and the top landing girders in position, the workmen attacked the high-level footway. This was built out from both towers simultaneously on the over-hang principle. First, the portions of the cantilevers immediately over the towers were erected and anchored to the shoreward columns. Then cranes were placed on the completed portions and moved forward to add fresh plates until the cantilevers had reached the point where the central suspended girder began. As at the Forth Bridge, this was built on to the cantilever ends, to which it was attached by temporary ties, and when the centre plates had been made secure, the ties were cut, allowing it to ride free at each extremity. Throughout the construction of the upper footway the greatest care had to be observed to prevent rivets, fragments, and tools falling into the river below to the peril of passengers on passing vessels.

Along the upper boom of the footway run the great ties connecting the suspension chains at their river ends. Each of the two ties is 301 feet long, and composed of eight plates 2 feet deep and 1 inch thick, terminating in large eye-plates to take the pins uniting them to the suspension chains. The construction of these chains was one of the most interesting and at the same time most delicate parts of the

whole undertaking. Each chain is composed of two parts, or links; the shorter dipping from the top of the abutment tower to the roadway, the longer rising from the roadway to the summit of the main tower. The links have each a lower and upper boom, connected by diagonal bracings so as to form a rigid girder. They were built in the positions they had finally to occupy, supported on trestles, and were not freed until they had been joined by huge steel pins to the ties crossing the central span and to those on the abutment towers. In order that the reader may have a clear conception of the action of the ties and chains, we will personally conduct him from end to end of the series. At the north end of the bridge is a huge mass of concrete surrounding an anchorage girder 40 feet long, 4 feet wide, and 4 feet deep, to which is attached a land tie springing up to the shore edge of the abutment top. At the anchorage end the tie is joined by a pin, 2 feet in diameter, to the girder, and at its upper end to the horizontal links crossing the abutment tower. The tie is built up of twelve plates 21 inches wide and nearly an inch thick. The link plates are 5 to 5½ feet wide and ⅞ inch thick and 22 feet long. At each end they rest on roller bearings moving over 3-inch steel plates very carefully levelled. Then comes the short link of the chain, attached by eye-plates and a steel pin, 2½ feet in diameter, to the tie and also to the lower end of the long link, at which point both are joined to the girders of the roadway. Passing up the long link we reach the top of the towers

and note the great pins and roller bearings at each end of the 301-foot ties. Then down the south long link to the roadway, up the short link, and over more roller bearings to the last section of the series—twelve plates 35 inches wide secured by rivets to the south anchorage girder, which is of larger dimensions than its northern fellow. This arrangement of chains, links, and ties permits a slight amount of horizontal motion to compensate the stresses of unequal loading on the two suspension spans, and the alterations in the length of the metal connections in varying temperatures. Roller joints are also made in the flooring of the side spans at each end and at the junction of the links to allow for longitudinal expansion and contraction.

The boring of the pin holes was a matter of great delicacy and considerable difficulty. The holes in the eye-plates of ties and chains had been cleared to within half-an-inch of their final diameter before leaving the contractor's works at Glasgow, and the finishing touches were added when the plates were in position. The labour of expanding out the holes to their full diameter was equivalent to boring a hole 2 feet 6 inches in diameter through *65 feet of solid steel;* and most of this boring had to be done in somewhat awkward positions at the top of the main towers and abutments, whither it was necessary to transport engines, boilers, and boring tools. The fixing of these generally occupied as long a time as the actual boring, since the greatest accuracy had to be observed throughout the process.

The roadway of the suspension spans is carried on cross girders, 61 feet long, weighing 22 tons. At each end they are connected by 6-inch pins to the suspension rods hanging vertically from the chain links. The rods are from $5\frac{1}{2}$ to 6 inches in diameter, and furnished with a screw-coupling at their centres to enable the accurate adjustment of the girders to the true level of the roadway. Before leaving the works each rod had been subjected to a tension of 200 tons, so that of their sufficiency there can be no doubt. Longitudinal girders of smaller section were then laid on the transverse girders, and on these again corrugated floor plates, afterwards filled up with concrete to form a slightly convex surface, over which wood paving blocks were placed.

We may now turn our attention to the central span of the roadway, which forms, perhaps, the most interesting part of the whole structure.

Each bascule, or leaf, of the drawbridge consists of four parallel girders, $13\frac{1}{2}$ feet apart, and about 160 feet long. When lowered it projects horizontally 100 feet towards the opposite tower, spanning exactly half of the opening. The point of balance is a solid pivot, 1 foot 9 inches in diameter and 48 feet long, that passes through the girders 50 feet from their shore ends. The pivot is keyed to the girders, and rotates on roller bearings carried by eight girders crossing the piers horizontally from north to south, themselves borne on girders under their ends.

The chief difficulty attending the erection of the

bascules resulted from the condition compelling the contractors to leave a clear way of 160 feet between the towers. Under other circumstances the girders might have been completed before being brought into line and connected together. As it was, the engineers first built the portions on the shore side of the pivot, added a short section of the river side steelwork, and launched the incomplete girders from the main stage close to the piers into the bascule chambers. A temporary steel mandrel was inserted to carry their weight while they were turned into a vertical position, and then withdrawn to make room for the permanent pivot, weighing 25 tons. The outer ends were added to until a point 53 feet from the pivot had been reached, and work in this direction then stopped until the raising and lowering of the leaves for purposes of adjustment had been concluded; after which the girders were completed vertically.

The leaves are moved by means of pinions (or cog-wheels) engaging with racks fixed to the edge of two steel quadrants riveted to their two outside girders. The accurate attachment of the racks was a somewhat difficult business on account of the confined space in which the men had to work.

To preserve the balance of the bascule it was necessary to load the shorter, or inner, arm with counterpoises, consisting of 290 tons of lead and 60 tons of iron enclosed in ballast boxes at the extreme ends of the girders. The function of the raising gear is merely to overcome the inertia of the 1200 tons of

the leaf, and the friction caused by wind pressure on the exposed surface. In designing the hydraulic machinery allowance was made for a wind pressure of 56 lbs. to the square foot, which would produce a force of 140 tons acting with a leverage of 56 feet.

The source of power is a building on the east side of the southern approach, where are stationed two large accumulators with 20-inch rams loaded to give a pressure of from 700 to 800 lbs. per square inch. An accumulator is the hydraulic counterpart of the reservoir bellows in an organ. It ensures a steady pressure, as its capacity is greater than that of the engines it operates; and since the pumping engines can be constantly at work filling it, there is always a plentiful supply of energy stored against the periodical opening and shutting of the bascules. The water is led through two 6-inch pipes, provided with flexible joints at points of movement, to the two sets of engines on the south pier; and to those on the north pier through continuation pipes passing up the south tower, across the footway, and down the north tower. After use, the water is returned through a 7-inch pipe to the pumping engines placed in two of the arches forming the southern approach to the bridge.

The engines are duplicated on each pier to avoid the inconvenience that would result from the breakdown of a single installation. The power of the engines is transmitted to the racks through a series of cog-wheels, which increase the effective pressure

of the pistons almost sevenfold. Hydraulic energy is also used to work the two hydraulic lifts in each main tower, and to shoot home and withdraw the four locking bolts at the outer extremity of the southern leaf.

In this connection the following extract from Mr. J. E. Tuit's fine book on the bridge will be of interest. "Every precaution has been taken so that the operation of opening and shutting the bridge shall be rendered as safe as possible. By an automatic arrangement attached to the hydraulic engines on the piers they are caused to close the valves which admit the high-pressure water just at the end of the operation of raising or lowering the leaves, so that even if the man in charge were to make a mistake through an error of judgment, or be prevented from attending to his duties, the leaves would gradually bring themselves to rest either in a vertical or horizontal position without the least chance of any catastrophe. As a still further precaution, however, hydraulic buffers are fixed in such positions that if the men in charge lost control of the bridge, and at the same time the apparatus above alluded to for bringing up the motion of the leaves were to fail, their impact would be taken by these buffers, which would bring them to rest in the same manner as that in which the hydraulic cylinders that are attached to heavy guns take up the recoil."

In cabins at the east and west ends of each pier are indicators to tell the men in charge whether the

accumulators are full before starting the engines, and whether the locking bolts are in their proper position. Further provision is made to prevent the raising of the bascules before they are cleared of traffic. The policemen in charge have to stretch a chain across the entrance to each pier. As soon as the chain is fixed, the man carrying it will be able to turn on the water to a small cylinder that draws it tight and at the same time releases the locking arrangement of the levers in the cabin. So that until the chain has opposed a barrier to the traffic, it is impossible to draw the locking bolts at the centre of the span.

The masonry of the towers is independent of the steelwork that it encloses. In fact, great care has been taken that there shall be no adhesion between the two substances. This part of the structure, carried out by Messrs. Perry & Co., calls for no special attention here, though it impresses itself favourably on the eye of the spectator. Objections have been raised to the external masonry on the ground that it is a "hollow sham," but we fancy that were the covering suddenly stripped away, so as to expose the steel skeleton beneath, many objectors would be silenced. The general opinion is that with so many metal structures exposing the nakedness of their outlines the London Corporation is to be congratulated on having thus boldly made a concession to the æsthetic tastes of the community which does not detract from the value of the bridge as a utilitarian erection. The cost of construction was

enhanced, but the result is one of which Londoners will be proud in years to come.

The Tower Bridge, typical of modern engineering skill, has an interesting connection with the old London Bridge—itself a mechanical triumph considering the science of the time—built towards the end of the twelfth century. That bridge, which stood the wear and tear of nearly 700 years, was endowed with certain lands which, with the growth of London, became extremely valuable, and are now known as the Bridge House Estates. The revenue from them has enabled the Corporation of London to rebuild the London Bridge, throw another across the Thames at Blackfriars, and also to construct the subject of this chapter.

We may conclude the account by a few figures. The bridge is exactly half a mile long, including the approaches, the side spans each occupying 270 feet clear. Its extreme height, measured from the bottom of the foundations to the summit of the main tower ridge-tiles, is 293 feet. The roadway of the side spans is 35 feet wide, flanked on each side by a 12½-foot paved footway. In the central span the widths are reduced by 3 and 4 feet respectively. Its construction, which occupied eight years, consumed 235,000 cubic feet of granite and stone, 20,000 tons of cement, 70,000 cubic yards of concrete, 31 million bricks, and 14,000 tons of iron and steel. The columns on the main piers and abutments required *five miles* of steel plates.

The total cost was estimated at three-quarters of a million pounds, of which the bridge itself represents rather more than half a million.

Sir J. Wolfe Barry, the engineer responsible for the construction, includes among his other important works the great Barry Dock near Cardiff, and the completion of the Inner Circle Railway between the Mansion House and Aldgate stations.

CHAPTER VI

AMERICAN BRIDGES

THE second place among monster bridges is held by the Brooklyn Suspension Bridge, connecting Manhattan Island, on which stands New York Proper, with Long Island. Previously to 1883 New York, with its population of two millions, and Brooklyn, counting a million inhabitants, were kept in communication across a narrow strait, 12 miles long, opening into Long Island Sound, known as the East River, by a number of steam ferries, one of which alone transports 22,000,000 foot passengers and 1,100,000 vehicles annually.

With the growth of population the absence of some permanent connection between the two islands was so severely felt that it was determined to link the two with a bridge of such a height above the water as to offer no obstruction to the shipping passing down the Sound to New York Harbour. The spot selected for the bridge is at the southern end of the East River strait, where it narrows down to a width of rather more than a quarter of a mile.

In deciding on the suspension type, American engineers had two good precedents—the Ohio River and Clifton Suspension at Niagara, which then held

the record in point of span. The Ohio Bridge at Cincinnati had a clear leap of 1000 feet; while that at Niagara measured 1268 feet between the centres of the towers, standing on either side of the gorge below the Falls. This bridge, opened to traffic in 1869, as a result of but twelve months' work, hung from two cables 1888 feet long, passing over rollers on the summit of the towers, which were built of wood strengthened by massive iron frames. The cables each contained 931 wires, $\frac{1}{7}$-inch diameter, twisted into seven ropes. When loaded with an average amount of traffic the bridge weighed 360 tons. To prevent excessive lateral oscillation strong steel guy ropes were strung from various points on the structure to anchorages on the side of the gorge. After standing and doing useful service for many years, the bridge was destroyed by one of the tremendous hurricanes that periodically sweep down the Niagara gorge as through a funnel.

There remained, however, the Niagara Railway Suspension Bridge, completed in 1855. This has a span of 821 feet, the track passing 245 feet above the river. It should be explained that the lower chord of the bridge is a girder with two floors, the upper of which carries the railroad, while the lower serves for foot and ordinary vehicular traffic. As originally constructed two masonry towers bore the weight of the four cables—each containing 3640 iron wires—that support the girder. After twenty-six years of wear it was discovered that these towers had

been bent inwards to a dangerous extent, owing to the rollers on which the cable saddles work at the tower tops having become clogged with cement. The engineers therefore built iron skeleton towers outside the masonry, and without in any way interrupting the traffic of the bridge, transferred the cables from the stone to the iron supports by means of powerful hydraulic jacks. This is a most interesting feat, and probably unique. When the bridge was in course of construction Robert Stephenson, engaged on the Victoria Tubular Bridge at Montreal, said to the designer of the Niagara Suspension—Mr. John A. Roebling—"If your bridge succeeds, mine is a magnificent blunder." The light American structure did succeed.[1]

The Brooklyn Bridge, like that at Niagara, is carried on four main cables. The supports are two huge towers, rising 272 feet above high water. At the river level they measure 140 feet broad by 50 deep, which dimensions decrease to 120×40 feet at the summit.

On the New York side the masonry is carried down to rock 78 feet below water level, giving the tower a total height of 350 feet. The masonry built into the two towers aggregated 85,000 cubic yards. The central span is $1595\frac{1}{2}$ feet. Between the towers and the anchorages are two 930-foot spans; and beyond these approaches that add 2534 feet to the total length—5989 feet, or about a mile and a furlong.

The most interesting feature of the bridge is the

[1] "The Railways of America," by Thomas M. Cooley.

cable work. Each of the four cables, anchored at either end to massive 23-ton plates, embedded in huge masses of masonry, each representing more than 44,000 tons, contains 5296 galvanised steel wires, which were carried separately from tower to tower, and bound up together in a parallel formation into a cylinder 15¾ inches in diameter.

The breaking strain of a cable is 12,000 tons. As each strand is 3572 feet long, about 1200 miles of wire were used in the cables.

These support six parallel steel trusses, on which is laid the roadway, 85 feet wide, divided into two carriage-tracks, two tramways, and one footway. The bridge rises towards its centre on a gradient of 3¼ per cent, the headway increasing from 119 feet at the towers to 135 in mid-channel.

The bridge cost $15,000,000, two-thirds of which was contributed by the Brooklyn municipality, and one-third by that of New York. It was begun in 1870 and opened to the public in 1883. Upwards of a quarter of a million people cross the bridge daily; but so great is the traffic between Manhattan and Long Island that three more bridges are in course of construction across the East River. These will, when completed, be in the first rank of such structures, and formidable competitors in regard to size with the Brooklyn Bridge.

A traveller in the United States is struck by the versatility of the American bridge-builder, whose genius develops most happily towards the erection

The Brooklyn Bridge, New York.

This is the largest suspension bridge in the world having a span of 1,595½ feet. The four suspension cables can support 48,000 tons.

[*To face p.* 130.

of light, airy viaducts spanning many of the valleys through which the great network of railways run. The States have now nearly 200,000 miles of track laid, and on the average there is one span of metallic bridge for every three miles of railway, giving a total of over 63,000. The increase in weight of locomotives and rolling-stock has led to the renewal of many of these bridges, by the substitution of more substantial work. And the rapid extension of existing systems constantly demands the manufacture of new bridges. Consequently the demand has driven manufacturers to standardise their patterns, and arrive at a distinct understanding with the railway engineers that, except in special cases, where divergence is unavoidable, all bridges ordered shall conform to certain stereotyped designs, which have been decided upon after much experimentation.

The American bridge-building Companies, thanks to this scientific arrangement, and the large number of orders that they are called upon to fill, have advanced the practice of bridge-making to a point that enables them to compete favourably with the manufacturers of other countries. The Yankee railway engineer gives measurements to the bridge Company, which by long practice knows just what is required to meet a particular case, and turns its mechanics, armed with all manner of labour-saving tools, on to cheaply made steel. In a few weeks or months the bridge is ready for delivery, the makers confident that when the pieces are assembled *in situ* they will come

together "like a clock." Very probably the Company does the erecting as well, so that after the order is given the railway Board's part of the work is confined to handing over a cheque to the proper amount, when the bridge has been passed by their engineers.

On American railroads the trestle bridge is a very common object, often towering to a giddy height, that dwarfs the giant locomotives passing overhead. In 1890 there were in the States 147,187 wooden trestle spans, aggregating 2127 miles of track. These, as liable to insidious decay and danger from fire, are being replaced by steel structures as fast as is possible. A notable instance is the Portage Viaduct on the Erie Railway, New York, crossing a river 234 feet above the bed. The old viaduct contained more than a million and a half feet of timber, arranged in piers formed of three grouped trestles. This was burned in 1875, and in its stead now stands a remarkably slender-looking viaduct of wrought iron, weighing but a small fraction of the wooden structure.

The same railway boasts another remarkable viaduct, the Kinzua, 2400 feet long and 305 feet high. It was built by Messrs. Clarke, Reeves & Co., in the short space of *three months*, without the use of any staging or ladders. The original spider-like supports have recently been replaced by steel trestles of a more solid nature, better calculated to sustain the great increase of rolling-stock weight.

Outside the country of its birth the American bridge is making headway. In recent years British

builders have several times felt their inability to compete with their transatlantic cousins, when creation and erection has to be hurried through. To take three notable examples. The Atbara Bridge, seven spans of 147 feet, was tendered for by American makers at £10, 13s. 6d. per ton; construction to take six weeks and erection eight weeks. The nearest English tender showed £15, 15s. per ton, and twenty-six weeks. The Uganda viaducts, East Africa, also fell to American makers, since their price was but three-fifths of the English figures. And in the third instance, that of the Gokteik Viaduct, Burma, their price was little more than a half that of British makers, and the contract time one year as against three years. These examples show how unequal is the competition, owing largely to the conservatism of English methods, and the imbecilities of trades-unionism in the British Isles. To "keep his end up" the British manufacturer will need to consign much of his machinery to the scrap heap, adopt standard designs, and instil a spirit of greater enterprise into his employés.

The Gokteik Viaduct, as the loftiest trestle erection in the world, and among the latest born, deserves special notice. It affords a typical illustration of American methods.

The Burma railway, running from Rangoon to Mandalay, a distance of about 400 miles, has lately been extended in an easterly direction through the Shan States to Lashio, *en route* to the Kunlon Ferry on the Salween River, following the track over which in

Marco Polo's time the Chinese armies marched to Mandalay.

Eighty miles east of the latter town is the Gokteik Gorge, with an average depth of 1300 feet, eaten out by the Chungzoune River. It was first proposed to cross this formidable obstacle by means of short rack railways on the Abt principle, which should lower trains from the high ground to a point in the gorge where huge blocks of limestone have fallen into the glen to form a natural bridge 500 feet above the river. A viaduct 80 feet high and 500 feet long would suffice for the crossing.

Eventually it was decided to flatten the grades of the approaches to 1 in 40, and raise the viaduct level to over 300 feet above the natural bridge. It should be said of the approaches themselves that they pass through very rough country, where the gradients are too steep to admit of curves. By means of switch-back reversing stations every two or three miles the train clambers slowly upwards in a zigzag course, on the edge of awful precipices. On the eastern side of the gorge the line still sticks to steep hillsides, passes through two tunnels and heavy cuttings, and then twists upwards by help of three semi-circular loops.

The viaduct was designed by Sir Alexander Rendel & Co., consulting engineers to the Burma Railways Company. The contract fell to the Pennsylvania Steel Company of Steelton. Our American cousins, said Sir Frederic Fryer, Lieutenant-Governor of Burma, at the opening ceremonies, obtained the

contract because they were able to submit a far more favourable tender than any English firm, both in point of cost and of time.

Within four months of the signing of the contract the first shipload of material was despatched from New York. Two months later it arrived at Rangoon. The transport of 4332 tons of steel over a line that had suffered severely from the 15-foot rainfall of the wet season was much delayed; but in spite of obstacles erection commenced in October.

To facilitate the classification and separation of the various parts and the handling of them by ignorant natives, each truss, girder, and column was painted a distinctive colour, and the joints when shop-assembled were streaked with special combinations of stripes on each adjacent piece. Along with the bridge material came pneumatic reamers and riveting hammers, hoisting engines, derricks, telephones, and last, but by no means least, thirty-five American workmen.

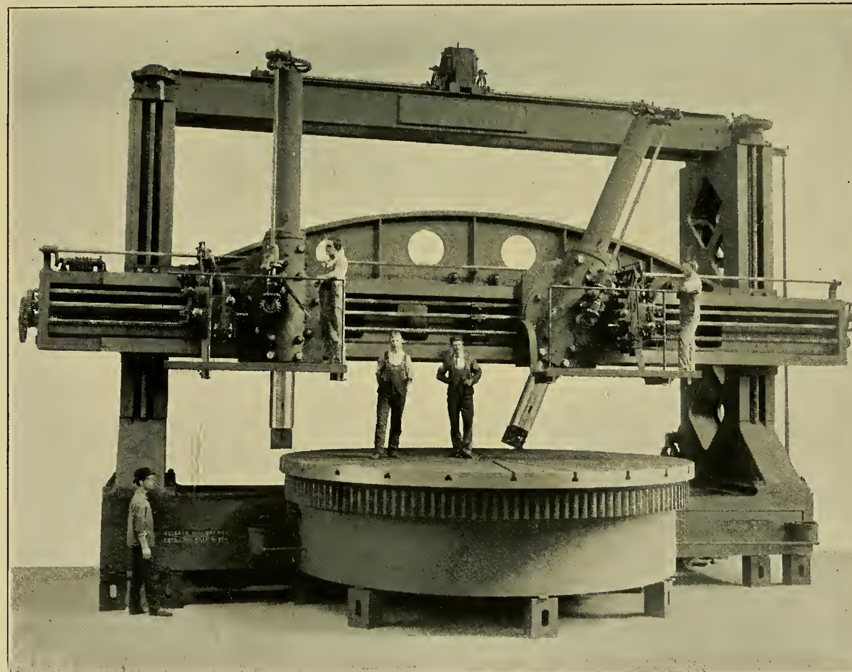
To aid in the erection a temporary line was laid in zigzags down the side of the gorge; this carried material to the foot of the viaduct, and also helped the transport of rails, sleepers, and even two locomotives (in pieces) to the further side, where 35 miles of track were laid during the construction of the viaduct.

From Steelton to Gokteik is 10,599 miles, an almost, if not quite, unprecedented distance to send the ready-made up parts of so large a structure. As fast as the metal arrived at the bridge-end it was whipped out of the metre-gauge cars by great steam derricks, which

handed them over to smaller derricks for sorting and storage. At times the press of work was so heavy that the trucks, immediately they were emptied, were picked up by the 15-ton crane and set down on the bank in piles, many feet below the track, to make way for loaded cars.

As soon as sufficient stuff had accumulated the "traveller" was erected at the south end of the bridge. This machine, which plays so important a part in American bridge building, and is largely responsible for the celerity of operations, is a large framework, the rear end of which is anchored to a completed section of the structure, while the forward and larger part overhangs and acts as a crane through which parts of the next section are lowered into place. The Gokteik traveller was 24½ feet wide, 60 feet high, and 219 feet long, with an unprecedented overhang of 165 feet. Cars running along the track transferred joists and trusses to the running tackle, which quickly let them down and held them in position while the riveters, mostly natives, fixed them. Some British and German sailors proved very useful on the traveller and topmost points of the rising towers, and set a very wholesome example to the 350 odd coolies engaged.

Now for a few figures about the bridge. Its total length from abutment to abutment is 2260 feet. For 281 feet at one end and 341 at the other, it is curved to a radius of 800 feet. The intermediate 1638 feet runs tangentially (in a straight line) at a height vary-



From a photo by] [*Messrs. Wm. Sellers & Co., Philadelphia.*

A Giant Lathe, which will bore or turn objects 25 feet in diameter.

The casting or forging to be treated is attached to the horizontal table, which slowly revolves while the workmen, by means of the sliding guide and its attachments, apply the cutting-tools held in the vertical bars.

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ing between 130 and 320 feet above the natural bridge and valley slopes. There are seventeen spans, ten 120 feet long, seven 60 feet long. The fifteen trestles, or towers, each of four columns (with one exception), are 24½ feet broad at top, and widen towards the bottom with a batter of 5 in 24. The trestle is 40 feet long, and is divided into storeys 35 feet high, which are braced diagonally. At the highest point of the viaduct, over the natural bridge, there is a double tower 80 feet long, with six columns 320 feet high. The 120-foot girders are of the lattice type, the 60 and 40-foot plate-sided, 42½ and 60¼ inches deep respectively.

The viaduct will eventually carry a double track, besides a footwalk for pedestrians. At present accommodation for the footwalk and one set of rails only has been provided; the other girders and trusses necessary for completion will be added at some future time.

The men worked from 7 to 12 A.M., and 1.45 to 6 P.M., except on such days as the furious monsoon blew through the gorge, or the heavens emptied themselves in deluges of rain. Under favourable conditions the structure rose with astonishing speed, some of the 200-foot towers going up in three or four days. The double tower consumed a month, as its immense height rendered construction more dangerous, and consequently less easy.

As soon as a tower was finished, the big girders for the space intervening between it and that on which

the traveller rested were swung out and fixed. Then followed horizontal stringers, cross floor beams, ties, and rails. These placed, the huge 100-ton framework rolled forward to the end of the new span, and commanded another masonry pier, whence a new tower soon began to rise.

On November 1, 1900, after nine months' labour, the last of the 200,000 field rivets was driven, and the Gokteik Viaduct stood complete. As 800,000 rivets had already been closed in the shops, the total shows just one million. It is a striking testimony to the thoroughness of American workmanship that 232,868 separate pieces shipped from Steelton fitted with wonderful accuracy when assembled in the Gorge.

The bridge cost the Railway Company £60,125; and it is considered that they have received good value for their money. Englishmen naturally regret that so important a contract should have passed into alien hands; but they will not grudge the praise due to the pushful American for a fine work, skilfully and quickly performed.

CHAPTER VII

THE TRANS-SIBERIAN RAILWAY

On the 9th of November 1901, the following telegram flashed along the wires from M. Witte to his Imperial master, the Czar :—

"On May 19, 1891, your Majesty at Vladivostock turned with your own hand the first sod of the Great Siberian Railway. To-day, on the anniversary of your accession to the throne, the East Asiatic Railway is completed. I venture to express to your Majesty, from the bottom of my heart, my loyal congratulations on this historic event. With the laying of the rails for a distance of 2400 versts, from the Transbaikal territory to Vladivostock and Port Arthur, our enterprise in Manchuria is practically, though not entirely, concluded. Notwithstanding exceptionally difficult conditions, and the destruction of a large portion of the line last year, temporary traffic can, from day to day, be carried on along the whole system. I hope that within two years hence all the remaining work to be done will be completed, and that the railway will be opened for permanent regular traffic."

To which the Czar replied :—

"I thank you sincerely for your joyful communica-

tion. I congratulate you on the completion within so short a time, and amid incredible difficulties, of one of the greatest railway undertakings in the world."

Ten years. Four thousand miles of railway laid down. More than a mile a day: a record.

Europe and Western civilisation at the one extremity, China and Eastern civilisation at the other. In between the greatest of the continents, and across that continent the unbroken (save for a few miles) band of iron.

A huge country—covering five million square miles —of swamp and forest and rich corn land, and mountains, and deserts. A country of intense cold and great heat. A country outwardly wretched, but hiding in its bosom treasure incalculable. A country of mighty rivers flowing from the central mountains of Asia to the Arctic Ocean, frozen solid half the year, but at certain seasons among the most magnificent waterways of the world. A country that was once inhabited by a great population, and then for ages the abode of a few wandering tribes; now receiving fresh life from tens of thousands of emigrants, who pour into it from Russia over the iron way. A country, in short, of which, but a few years ago, we knew little whatsoever; even less that was enticing, or creditable, or propitious. We regarded it as a mere dumping-ground for Muscovite criminals, chained to the deadly labour of the mines, or cast abroad to fare as best they might in the great solitudes. But now it has suddenly leapt into notice as a new Land

of Promise, to which are turned the eager and inquiring eyes of half the world.

The story of Siberia begins with the picturesque figure of Yermack—"the Millstone"—a boatman who plied his trade on "Little Mother Volga," as the Russians fondly term their mightiest river. He fell into a bad habit of piracy, and after a series of murders was forced to flee for his life to the Urals, where he met a family of traders who were preparing an expedition to Siberia, the land of the precious sable. He entered their service as trapper, and in 1581 started for hunting-grounds far away in the heart of North Asia. Many doughty deeds were wrought by Yermack and his followers in their struggle with the Tartar tribes, and his victories over the savage tribes brought him pardon and great honour. But his enemies killed him at last, and other leaders took his place, penetrating further and further westwards in search of sable, suffering terribly at times, but still pushing on the limits of the Empire to Tobolsk, Yeneseisk, Irkutsk. In 1650 the gallant Khabaroff conquered the territory of the Amur, and brought the Russian standard to the Pacific Ocean. Then followed a period of rest for 200 years, at the end of which General Mouravieff formally annexed the district, which by the Treaty of Pekin, 1861, passed into Muscovite hands for ever.

The Russians now had an important province in the Far East, washed by the waters of a great ocean, and traversed by a noble river. They determined

that it should be joined to their European possessions by something more commodious and more safe than the ill-made, bandit-infested post-road that wound its muddy or frozen length across the steppes and mountains.

America had been spanned by the iron way. Why not Siberia? The engineering difficulties arising from natural configuration would not be insuperable.

Jogging the Russian elbow was the Anglo-Saxon engineer. It is interesting to note that the scheme of laying a ribbon of steel across the Asiatic continent first matured in English and American brains. As far back as 1857 an American named Collins offered to connect Irkutsk to Chita, some hundreds of miles east of Lake Baikal. The following year an English syndicate proposed a railway from Moscow to the Sea of Japan, and undertook its construction for a price. But the Russians preferred to wait until such time as their own engineers could cope with the Herculean task. For forty years they planned and surveyed, gathering experience from the great railway pushed eastward to Merv and Sarmakand. So strong was their faith in the potentialities of the Great Lone Land of Asia as a dwelling-place for their teeming millions, that when at last the work was taken in hand they faced an enormous expenditure despite the financial straits in which their country was sometimes involved.

The sum of £40,000,000 was voted for the construction of the line. In order to expedite its progress,

its total length, from Cheliabinsk, on the European frontier, to Vladivostock on the Japan Sea, was divided into the following divisions :—

1. Cheliabinsk to Obi, the *Western Siberian* section, 800 miles long.

2. Obi to Irkutsk, the *Central Siberian* section, 1137 miles.

3. Irkutsk to Myssovaia on the south-east shore of Lake Baikal.

4. Myssovaia to Stretensk, the *Trans Baikal* section, 686 miles.

5. Stretensk to Khabarofsk on the Ussuri River, the *Amur Section*, 1326 miles.

6. Khabarofsk to Vladivostock, the *Ussurian Railway*, 478 miles.

The first sod was cut and the first barrow-load wheeled at Vladivostock by the present Czar, who in 1891 as Czarewitch made a grand tour of the East. A start was made at the Cheliabinsk end in the following year. Ever since construction has steadily progressed in the face of physical and other difficulties at a pace which eclipses the laying of the great trunk lines of the United States and Canada.

In December 1895 the Trans-Siberian was completed to Omsk; in 1896 to Obi; in 1896 to Irkutsk, 3371 miles east of Moscow. Simultaneously the Ussurian section had reached Khabarofsk, so that in seven years 2503 miles of rail had been opened to traffic.

Stretensk was reached in July 1900, and there the

original scheme terminated. To avoid carrying the line along the Amour an arrangement was come to with the Chinese Government in 1896, by which the engineers were given rights to drive the track across North Manchuria in an almost straight line to Vladivostock; and in 1898 the Russo-Chinese Bank (*alias* Russian Government) obtained a concession to make a branch due south from the Manchurian section to Port Arthur on the Gulf of Pechili. These sections were pushed forward with the greatest possible speed, owing to political events in the Far East, which demanded the presence of large bodies of troops to protect—or extend—Russian interests.

The Trans-Siberian Railway, as measured from Cheliabinsk, has a length to Vladivostock of 3967 miles, and to Port Arthur of 4242 miles. If we add to this the Ussurian system, and the section running north-east from Cheliabinsk to Kotlass on the Northern Dwina, we arrive at the grand total of nearly 6000 miles, or about double the mileage of the "Canadian-Pacific." The railway in its course crosses the upper waters of the Obi, Yenesei, Lena, and Amur at points where they begin to be easily navigable by vessels of considerable size. These rivers, each between 2000 and 3000 miles long, exclusive of tributaries, are being connected by canals, which will form the most splendid system of water communication in the world, and act as feeders to the great railway at many points. Their utility during the construction of the latter has been incalculable.

Three names are conspicuous among the many connected with this gigantic undertaking: those of the Czar, who is President of the Railway Committee; of M. Witte, the Minister of Finance; and of Prince Hilkoff. Of these the second was once a station-master on the Southern Russian railways: and the third worked under an assumed name as a paid employé on the railroads of the United States, where, in the shops and elsewhere, he gained the great store of practical knowledge that he is now turning to such good account.

The chorus of admiration evoked by the successful termination of their labours has been unanimous. Yet questions have been raised about two points, on which criticism has laid a finger. To the outsider it is a matter of surprise that the railway should have given a wide berth to Tobolsk, the capital of Western Siberia, and to Tomsk, the capital of the Central Provinces. These towns will be served by branch lines, but it is open to doubt whether in the future their importance will not decline, and new towns situated on the main track take up the mantle that has fallen from their shoulders. Engineers of other nations also wonder why rails of such lightness at 18 lbs. to the foot have been used, while 20- to 25-lb. rails are the common practice in Russia, and 28- to 33-lb. rails the rule in Europe and other countries. We must, however, remember that the need for economy was most pressing, and that in using the lighter rails the Committee have precedents in the United States,

where in many instances heavy metals are laid down only when traffic has assumed certain proportions. Already sections are being re-laid with 70-lb. rails, those they replace being relegated to the sidings which occur at frequent intervals throughout the system.

To gain an adequate idea of the immensity of the "Great Siberian," we should undoubtedly travel over it. A map, even on a large scale, is but a poor aid to the imagination. Omsk and Obi, to take an instance, seem but a few miles apart on paper, whereas a journey equal to that from London to Edinburgh separates them. Place one point of a pair of compasses at Cheliabinsk, and the other at Berlin. Describe a circle, and it passes through Lake Baikal, some 1500 miles from the journey's end.

We will, nevertheless, endeavour to gain some conception of what the traveller sees, by calling Aladdin's genie to our aid, and transporting ourselves to the terminal station at Moscow—the finest station of the old capital—from which a train is about to start on its 4000-mile trip.

A fashionable throng fills the waiting-rooms and buffets, for the departure of the Siberian express is still a novelty, and attended by more than the usual amount of bustle and leave-taking connected with a long journey. Russians are very proud of their express, which is indeed worthy of our close atten tion. In it the travellers will be confined for a fortnight at least, so we will see how their comfort

has been provided for. First we notice that the train is lit throughout by electric light, generated in a special compartment by a separate boiler and engine. Even the head- and tail-lights are fed from this source. One car is fitted up as a drawing-room, with luxurious chairs and couches, upholstered in soft leather, writing-tables, a piano, maps; another contains a restaurant, where a first-class meal may be had at all hours of the day, a beautifully fitted bathroom and an exercising machine. When you wish to retire for the night press the electric bell button, and a servant appears to make up the comfortable bed that is cunningly folded away during the day-time. Above the bed are levers to admit fresh air or hot water to the heating apparatus as you wish. The corridors that traverse the train from end to end are provided with filter ventilators which keep out the dust and let in oxygen. This *train de luxe* is put on by the International Sleeping Car Company; a guarantee for everything being all that the heart of traveller could wish.

At nine P.M. the engine gives a deep whistle, and draws out into the night, and on to the rolling steppes that stretch away monotonously east and west and south and north for hundreds upon hundreds of miles. Yet these are some of the greatest granaries of Europe. Large stretches are chequered with the green of the growing crop, or the gold of the harvest, or the grey of the stubble. Giant straw-stacks proclaim an abundant harvest past; threshed by the

trampling ponies of the peasant, and winnowed after the manner of the Israelites.

On, on, over the steppes to Batraki, where a splendid bridge, named in honour of Alexander II., crosses the Volga, with thirteen spans of 350 feet each —a total of nearly a mile. Then we roll into Samara, a city of 90,000 souls, whence a branch line runs south to Orenburg, with Tashkend as its ultimate objective. This region some years ago was swept by a fearful famine that carried off the population like flies, and covered the steppes with their graves.

Two hundred miles and we reach Oufa, a town of many churches and schools, hospitals and asylums for poor and aged, libraries and museums: a town of which the poorer classes are sunk in deep ignorance like their fellows in the rest of the empire. This is one of the anomalies of Russia—utter illiteracy hand in hand with splendid equipment for learning.

The train has now begun to taste the Urals, which heave themselves up between the vast plain of Russia, and the vaster Siberian plain beyond. The hillsides bristle with broad expanses of fir and birch forest, but the grey rock breaks through at the summit. We pass Zuleya, the famous iron district whence have come millions of tons of metal, and reach Zlatoust on the summit of the range. A few miles further on is the far-famed Stone of Parting—one of the most pathetic landmarks ever reared by the hand of man: a simple triangular obelisk, on one side the word "Europe," on another

"Asia." How many tear-stained, heart-broken partings has this dumb stone witnessed! How many thousands of chained convicts have defiled here, urged by the whip of Cossack, torn from the arms of the friends that gaze sorrowfully after them from beyond the limit of Europe.

We are soon on the down grade; the scenery merges once more into that of the steppes, here covered with high grass, birch trees, and small swampy lakes.

Cheliabinsk. The first station on the Siberian Line proper: the junction for the line that runs northwards through Ekaterinburg, Perm, Viatka, to Kotlass on the Dwina, from which port goods are sea-borne to England. This outlet of Siberian trade will be hugely developed in the future.

Before passing into Siberia let us endeavour to form an idea of that country, hitherto of darkness, now being brought to the light by the magic of the engineer. Physically, Siberia is divided into three great zones: the Tundra, or frozen swamps of the north, abode of almost perpetual frost; the Taiga, the most wonderful belt of forest on this earth, stretching for a thousand miles and more east and west between the Tundra and the most valuable belt of all—the Steppes, deeply covered by stoneless, dark earth, which with proper cultivation will become one of the greatest granaries of the world. Were Siberia but blest with a warmer climate, there would be no land to compare with it, such is its extent and variety.

So intense is the cold, reaching to 50 degrees below zero in many places, that even during summer the earth is still frozen hard but a few feet below the surface, while crops wave above. In winter the rivers are not merely covered with ice but actually frozen solid.

On account of the climatic conditions the engineers met with many and great hardships and difficulties. While constructing the Trans-Baikal section they had to blast the cuttings with dynamite, as the earth was congealed to the consistency of rock. At the stations water-supply pipes had to be laid in culverts provided with a heating apparatus, and masonry could be built only in artificially warmed shelters. The Ussurian railway was driven with the greatest difficulty through virgin forests of cedar and larch, intertwined with wild vines and creepers; and when made the track often suffered severely from the heavy floods that occurred during the best working season. Plague wrought havoc among the beasts of burden, and fever swept off many of the workmen. In the Kirghiz steppes, too, water and cold taxed the utmost exertions of the constructors. No less than 30 miles of bridges cross the many rivers over which the railway passes, and for hundreds of miles the track is protected from flood only by being raised on a 5-foot embankment above the surrounding country. In the mountainous districts of the Altai and Yablonoi the engineers had to overcome difficulties comparable to those encountered in the Rockies and Andes.

To return to Cheliabinsk, the quarantine station where all emigrants must show a clean bill of health. Our train progresses at a leisurely 15 miles an hour through the monotonous landscape, which the iron way traverses with mathematical straightness for several leagues at a stretch. Every verst we see the watchman—an ex-convict—step from his little hut and wave his flag to show that all is right on his "length." Every twenty versts or so we pass a wayside station—generally on a loop to give a clear passage to express traffic. As a rule the stations are well-built and clean, surrounded by neat palisades; each with its water-tower and storehouse, earthed up to the roof to keep out the cold. Now and then in the sidings we see a third- or fourth-class train full of settlers on the way to their new homes, crowded like sheep into windowless trucks. Or perhaps there are windows, gridded with bars, from behind which peer the faces of convicts bound for the prisons and mines of the interior.

A fine bridge, 2400 feet long, leads us across the Irtish into Omsk, founded by Peter the Great. It has been prophesied of Omsk that some day it will be the chief town of Siberia, as the centre of a great system of water-ways, and near important gold-fields and copper mines, and the even more valuable coal deposits of Pavlodar, where is said to be a seam *300 feet thick*, extending for miles. "Vast quantities of coke will be produced here, shipped down the Irtish to Tiumen, and thence transported to the Urals

for the ironworks—a supply the importance of which will be appreciated by those who know anything about the iron industry."[1]

A railway has been projected to run from Omsk southwards to join the system of Central Asia, which is also being pushed forward vigorously by the Russian military authorities. This would complete an enormous triangle, with corners at Samara, Omsk, and Tashkend.

Three hundred miles of track through the great corn-growing steppes bring us to Obi, the end of the W. Siberian section—opened in October 1896—which in three years has sprung from zero to a population of 14,000. Our next stopping-place is Taiga, another example of rapid growth, owing to its being the junction for Tomsk. This latter town, despite its fine University, electric light, and 50,000 inhabitants, may in a few years be eclipsed by its southern new-born neighbour.

The word Taiga tells us what to expect in our progress. The scenery changes. The steppe gives way to mile after mile of forest, one of the most valuable assets of the Czar in an age when the world's timber supply has sensibly diminished. We drop down into Krasnoiarsk—the city of the Red Rock—the chief town of the Yenesei Government, possessed of the finest gardens in Siberia, where imported trees fare badly. Like Omsk it is situated on a mighty river, the Yenesei, which rises in Mongolia and takes its broad course for 2500 miles to the Arctic Ocean.

[1] "All the Russias," by Henry Norman, M.P., p. 155.

By permission of] [*Sir W. G. Armstrong, Whitworth & Co.*

The "Baikal" Ice-Ferry, used on the Lake of the same name to transfer Trains of the Trans-Siberian Railway from one Shore to the other.

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Ships come hither direct from London. On the east of the town a fine bridge of six spans, each span 474 feet, clears the river. The separate spans were put together on the bank, and launched into position by means of rollers and a special crane.

We now rise to breast the Altai Mountains, which passed, we soon reach Irkutsk, the terminus of the Central Siberian.

Irkutsk, on the Angara, the great tributary of the Yenesei, is a curious mixture of new civilisation and barbarism. It owns a fine theatre that cost £30,000, and a good museum; a telegraph office, whence messages may be sent all over the world; an organised telephone service, stretching fifty miles into the country; an excellently equipped fire service; a noble cathedral; shops in which you may buy all the luxuries of the West; and a bank. It is also one of the three centres to which all gold mined in the district must be sent for tests in the Government laboratories. Since its erection in 1870 the laboratory has passed £60,000,000 worth of gold.

But, owing to the presence of escaped convicts, Irkutsk has been described as "the one place in the Russian Empire where a man cannot feel safe." To go alone in the streets after dark is risky, as the police cannot cope with the ruffians of the place. Consequently people retire indoors early, closely bar their doors, and before going to bed fire a revolver out of the window to warn would-be marauders and housebreakers what to expect.

A short journey from Irkutsk brings us to the most interesting spot on the railway—Lake Baikal. The "Holy Sea," as the Russians call it, is one of the largest fresh-water lakes of the world, yielding place in size only to Superior, Huron, Michigan, and Victoria Nyanza. It has an area of 14,500 square miles, and so great is its profundity that, though its surface is 1500 feet above sea-level, its lowest depths descend several thousand feet below the bosom of the Pacific Ocean. On all sides mountains gird it in with frowning cliffs and indent it with eighty capes. For the native it is an object of worship and superstition, since on the island of Olkon dwells Begdozi, the Evil Spirit, who must be appeased by sacrifice. From the north end flows out the Chilka, a tributary of the Lena; from the south-west the Angara, the main feeder of the Yenesei.

The waters are much vexed by storms, which raise waves 6 or 7 feet high. In November the lake begins to freeze, and for four and a half months is held in the grip of Winter under an ice coating 9 feet thick, traversed by huge cracks that make sleigh traffic risky and uncertain.

The lake is the most serious obstacle that the engineers had to face; for the mountainous nature of its setting renders the circuit of the south end a very arduous and costly task that will not be completed for several years to come. For present purposes the gap in the line is served by a train-carrying steamer—the *Baikal*—specially built for forcing a passage through

the ice. Jetties supported on caissons project into the lake at the termini, separated by 42 miles of water, and, by means of a platform adjustable to the varying level of the lake, transfer the train to the boat, where it is accommodated on one of the three tracks that are laid along the axis of the middle deck. The *Baikal* is a vessel of 4000 tons, driven by three engines of 1250 horse-power each, working two screws in the stern and one in the bow. The vessel was built by Sir William Armstrong, Whitworth, & Co. at the Elswick Works, Newcastle-on-Tyne; then taken to pieces and the parts delivered at St. Petersburg. Waggons transported the pieces—the heaviest weighing about 20 tons—to Krasnoiarsk, and sleighs continued the journey to Irkutsk, whence the parts were floated down the Angara to the lake. Russian workmen, superintended by English engineers, there assembled the parts and added the boilers, pumps, and other machinery.

The ice-breaker is 290 feet long, and of 57-foot beam. Ballast tanks, distributed in the double bottom, hold 580 tons of water. At the water-line she is protected by a belt of steel plates, reinforced with heavy wooden beams 2 feet thick. On the upper deck are spacious and comfortable saloons for the accommodation of 150 passengers.

In clear water the *Baikal* makes 13 to 14 knots an hour. Ice 3½ feet thick gives way to her. The forward screw scoops out the water ahead, and the stern propellers force the vessel up on to the

ice until her weight breaks through, her advance being 3 to 6 miles an hour. A second ice-breaker, the *Angara*, is 195 feet long and 34 in beam, and of equal speed but smaller ice-cleaving power. Like the sister vessel, she was transported to the lake in pieces and there assembled.

While on the subject of ice-breakers—among the most interesting of steam vessels—we may glance at the *Ermack*, built in 1898 for service in the Baltic. She has a displacement of 4000 tons; length, 305 feet; beam, 71 feet; depth, 42½ feet; 8000 horse-power; speed, 15 knots. Her shape is such that, when pinched in ice, she tends to rise, after the manner of Nansen's *Fram*. On her trial trip among Arctic floes she easily dealt with ice many feet thick; and in the Baltic she has been of the greatest use in extracting frozen-in vessels, including a warship.

East of Lake Baikal the line rises into the Yablonoi Mountains, attains a maximum elevation of 3412 feet, and descends to Naidalovo, the junction of the Stretensk branch and the main line, which reaches the Russian frontier at Nagadan. This is a little-explored country, inhabited by Mongols, of which the chief traffic is the tea-carrying trade. The line is well laid here on heavy rails, supported by ties bedded in cement. Beyond Kailar, a town of 3000 inhabitants, it crosses an elevated plateau to the great Kinghan range, and then drops once more to Kharbin on the Sungari river, which is the engineering headquarters of the Chinese railway. To this district legend assigns

the birthplace of Ghenghis Khan, who, in his many wars and invasions, is said to have destroyed five or six million human beings. In the beginning of the thirteenth century he overran Western Asia with steel and fire; and to-day the same elements have invaded his land in turn. But the steel is in rails and the fire in the furnaces of mighty locomotives.

At Kharbin we can take our choice of Port Arthur or Vladivostock, the former 500, the latter 350 miles away; though on the map we appear almost at the end of our travels. Selecting Port Arthur, we jog slowly along past Mukden, the largest town yet encountered, with its 200,000 souls. A short branch of 20 miles links it with the main-line.

Dalny, on the Gulf of Korea, is our next halting-place, and a unique city. For though streets and squares have been laid out, schools and churches provided, electric light and cars installed, there is as yet no population. It is a town quickly built for the future: one that may become a great port, thanks to its situation on an open harbour which never freezes.

At Port Arthur we end our roaming on the iron way. Here we see the "mailed fist" of Russia in the batteries bristling with cannon of all sizes, from the 12-inch monster to the 4-inch quick-firer; in the barracks to shelter large bodies of troops; in the torpedo boats darting in and out of the harbour under the shadow of the huge men-of-war; in the dockyards; and in the military carriage and accoutrements of every one we meet.

A hundred miles north of Port Arthur the Pekin branch diverges. Russia has thus a hold on the very throat of China. To-day a regiment may be in Moscow; in three weeks' time its officers may issue their orders within the walls of Pekin. This, then, is one of the real issues of the Siberian Railway—the immense leverage that it will give to the Muscovite in any struggle with the Mongolian. Over the iron track will roll all the martial arts and engines of the West. Is the time ever coming when the Mongolian will reverse the order of things aud pour his countless hordes again towards Europe, now so much nearer than in the time of great Ghenghis?

The Russians have spent, or will have to spend, upwards of 100 million pounds before their great line is in first-class running order.

Honour to whom honour is due—the railway is a magnificent scheme, carried through with indomitable perseverance.

But will it pay? This is the question asked by Russians, English, Germans, Americans—the world. There are those who are ready to utter Cassandra prophecies of broken finances, climatic deterrents to immigration, frontier troubles with the Chinese. But a far larger number see in the railway returns a promise of a bright future. It has been mentioned that the line was laid with light metals; this because the initial traffic was expected to be but moderate. What happened? Scarcely were the sections declared open than a rush set in. In 1898 100,000 tons of

goods accumulated on the western and central lines, waiting months to be forwarded to their destination. The line was utterly unable to cope with the immense body of merchandise thrust on to it. In 1899 the same thing recurred, 7000 waggons blocking the line. Consider these figures. In 1896 the Western Siberian carried 160,000 passengers, 69,000 emigrants, 169,470 tons of merchandise. In 1897, 236,000 ordinary passengers, 78,000 emigrants, 242,000 tons. In 1898 the figures increase respectively to 535,000, 133,000, 449,000.

The Central Siberian in the first year named carried 14,700 passengers; in 1898, 407,680. Merchandise increased from 16,350 tons to 250,816 tons.

Since 1898 the augmentation has continued. How could it be otherwise? On the one hand a new country, richer in gold than the Transvaal; richer in coal than any other country; richer in graphite than Ceylon and Cumberland; the greatest timber-growing country; a great future granary; bountifully stocked with valuable fur animals; a Midas treasure-house of iron, copper, tin, lead, silver, salt, precious stones; the coming paradise of the hunter and tourist; a present well-developed grazing and cereal country.

On the other hand, a vigorous Government bent on making room for the millions that in European Russia live in a wretched state of semi-starvation; capitalists of all nations eager to invest their wealth in enterprises that may yield a huge return; a world that

finds in the Trans-Siberian the shortest and quickest route from Europe to the Pacific.

The Russians promise that, when their grand line is in full working order, the journey from London to Shanghai will be possible in fifteen to sixteen days, made up as follows:—

London to Moscow . . .	3 days
Moscow to Vladivostock . .	10 ,,
Vladivostock to Shanghai . .	3 ,,

This at a cost of about £50, food included. By sea the same journey costs at present nearly double this sum, and occupies rather more than double the estimated time.

"The following will then be the shortest route between the United States and the Far East *viâ* Siberia, New York, Havre, Paris (London passengers will go *viâ* Dover and Ostend to Cologne), Cologne, Berlin, Alexandrovo, Warsaw, Moscow, Tula, Samara, Cheliabinsk, Irkutsk, Stretensk, Mukden, Port Arthur; and the total length of this journey (excluding the Atlantic) about 7300 miles, of which 297 miles will be in France, 99 miles in Belgium, 660 miles in Germany, 2310 miles in European Russia, and about 4000 miles in Asiatic Russia. These are the official figures."[1]

Another quotation bears on the same subject:—

"From January 1905 a *train de luxe*, composed solely of first-class carriages, will be run by the company from Warsaw to Moscow and Port Arthur; the

[1] From "All the Russias," by Henry Norman, M.P.

train will be run as many times weekly as the Company may deem advisable. The value of the new concessions obtained by the Company may be inferred from the fact that its northern express, its southern express, its eastern express, &c., unite all the capitals of Europe and Warsaw, where passengers will find Trans-Siberian carriages. The reason why a more thoroughly effective service of international *trains de luxe* will not be commenced by the company before 1905 is, that it is not until that year that a line running round Lake Baikal will be completed. When this line has been opened for traffic, and when the permanent way of the Trans-Siberian line has also been improved, an acceleration of the train service will be practicable. The Trans-Siberian line will not only be a means of transit between Western Europe and Japan and the north of China, but it will also be the shortest route between England and Australia. It is expected, indeed, that it will eventually be possible to reach Australia from London *viâ* Siberia in twenty-two days."[1]

We may here bid farewell to the "Great Siberian." But before leaving the confines of the Russian Empire, a word should be said of the great water schemes which are playing, and will play, as important a part in its development as the far-reaching tracks of the iron horse.

[1] *Engineering*, May 2, 1902.

For more than a hundred years after the time of Peter the Great, Russia depended for the transportation of her population and commerce on the 60,000 miles of natural waterway with which she is endowed. Her physical configuration is such that all her large rivers rise in the plateau of the Valdai Hills, thereby affording the engineer a unique opportunity for using his arts to the immense advantage of the country at but a small comparative expense. A total of 1000 miles of canals unites the head waters of the Volga, Don, Dnieper, Dwina, and Duna, enabling boats to pass from the Caspian to the White Sea, from the Black Sea to the Baltic, and from St. Petersburg to the foot of the Ural Mountains.

With the growth of the railway system has come a great expansion of canal mileage. It is to-day recognised that the era of the canal and canalised river, so far from being of the past, is but entering its period of greatest usefulness as the handmaid of the metal track. The Manchester Ship Canal, the Kiel Canal, the Corinthian Canal for sea-going vessels, the network of smaller channels for smaller craft that wrinkles the face of America, China, India, and Europe, are witness to this. Huge schemes are in the air, on paper, in progress.

The greatest of all these in Russia is the Baltic-Black Sea Ship Canal, some 2000 miles in length. A syndicate of French and Belgian engineers offered to cut a channel 28 feet deep from the Baltic to Kherson—an important port on the Dnieper—of such

amplitude as to float a heavy warship from one end to the other. The price asked was £140,000,000, too great for the present means of the Government, though in the future the plan will probably be carried out, and so pass into the greatest of all engineering feats. Further schemes connect the Black Sea with the Sea of Azov by a canal through the narrow neck joining the Crimea to the mainland, and the Black Sea with the Caspian, by uniting the Don with the Volga. A company has already offered to effect the connection for the sum of £8,000,000. The attempt was made two hundred years ago by the great Peter, and frustrated by the physical difficulties. These include the shallowness of the Don, which at its mouth is beset with shifting sand-bars. Here the powerful and effective steam dredger will have a fine field open to it in clearing away these troubles to navigation. The canal made, what possibilities would unfold themselves! The Volga, which, with its tributaries, numbers 8000 miles, is the home of great steamers of 6000 tons capacity, huge floating tanks of Baku petroleum, enormous timber rafts—15,000 come down annually—barges and small vessels innumerable. On its banks are Astrakan, Kasan, Nijni-Novgorod—where £40,000,000 changes hands at the great fair in a few weeks—and the old capital, Moscow. The Caspian is flanked on all sides by districts that will flourish by-and-by, and lies on the north of Persia, which country would be connected directly to the Mediterranean Sea by the proposed canal, and so

obtain a northern outlet to supplement the Persian Gulf on the south.

Nor do Russian plans stop at the Caspian. The conquerors of Turkestan would bend to their will the mighty Oxus, one of the most storied rivers in the world, and divert it from its present to its ancient bed; so that instead of seeking the Aral Sea, it may empty itself into the Caspian. Inasmuch as the Oxus (or Amu-Daria) is in places over a mile wide, has a volume three times that of the Danube, and draws its waters from the eternal snows of the Pamirs, the project is one that may be described as sensational. The deflection would lower the level of the Aral Sea, but would open a waterway from the whole world to the borders of Afghanistan, whither steamers already ply on the river itself.

Mention has already been made of the canal that links St. Petersburg with the Urals, which oppose a wall between the Russian and Siberian waterways. On the eastern side of the range are the Obi and Yenesei, joined by a canal, which renders navigation of large boats possible from the Urals to Lake Baikal, and thence to the very borders of China.

Some years ago a syndicate of private individuals tried to cut a canal through the Urals to supply the missing link between the Baltic and Mongolia. When a few miles had been finished the fatherly Government stepped in and declared that such a work was for the State to direct, and must wait for its completion until finances permit. There is a prospect that

at no far distant time we shall be able to float our house-boats on a holiday trip for 6000 miles in Russian territory through the hearts of two continents.

These projects — and feats — are indeed startling proof of the new leaven that is working in that wonderful mass of despotism, militarism, officialism, guiding grinding poverty and benighted ignorance with the tenacious enthusiasm and genius of master minds. At present the official commands, and the moujik — poor down-trodden machine — obeys; but when the leaven has leavened the whole lump down to the poorest peasant, what will the empire that has the Trans-Siberian, Trans-Caspian, Trans-Caucasian railways to its credit, not to mention a hundred works of comparable difficulty, have to fear from comparison with the mightiest nations that have ever been?

CHAPTER VIII

CAIRO TO THE CAPE

WHAT'S in a name? Little perhaps. But unite a couple of names into a catchword that neatly expresses the political wishes of a large body of people or a nation, and their influence may be great.

"Petersburg to Pekin" has been heard in Russian circles for years, and lo! the Trans-Siberian Railway.

"Berlin to Bagdad," cried the German, and we learn of schemes for a railway from the Prussian capital to the Persian Gulf. We shall see what will happen!

Of late years Englishmen, too, have not lacked their alliterative phrase. "The Cape to Cairo," or "Cairo to the Cape." Either way it tickles the ear, and is very suggestive. One sees in one's mind's eye the locomotive puffing through the *terra incognita* on which some little light has been thrown by Livingstone, Stanley, Grant, Speke, Grogan, and other intrepid explorers; puffing steadily ahead through forest and swamp, mountain and lofty plateau, beside great lakes and over mighty rivers, till it emerges on the sands of Egypt, or the more hospitable plains of Rhodesia.

Who first conceived a Trans-African railway it is

at this time hard to say. But we know who first brought the idea into prominence, and took decisive steps towards its realisation. That man was the great empire-builder, Cecil Rhodes. Essentially a man of vast schemes, he treasured the conception of a metal highway from one end of Africa to the other, on English soil throughout almost its entire length. The railway to Khartoum grew from military necessity. The Cape lines developed to keep pace with the needs of colonisation. Cecil Rhodes added Rhodesia to the British Possessions, and strained every nerve to traverse the new country with a line that should form an important link in the great chain; and, after vainly seeking aid from the English Government, started a Company to carry through his ideas. Furthermore, he approached the German Emperor, and obtained concessions—for a price—to carry his line through German territory to join the system of British Central Africa.

His untimely death has stilled the guiding hand, but the work is carried on, and doubtless in due time the word "finis" will be written to this important chapter in continental engineering, and we shall be able to book direct from Cairo to the Cape for the grand tour of Central Africa.

The work is stupendous, and the difficulties are great—especially the political. Through unlucky want of foresight the red portion of the map of Africa is severed by German and Belgian territory for a distance of some 350 miles. But for that break all would

be plain sailing, since, if need bids, the engineer will not be denied, as this volume endeavours to show.

Owing to this "foreign element" in the path of the Cape-to-Cairo, it cannot serve strategical ends. Starting, as it does, from the east end of the Mediterranean, it will never be able to compete against the direct sea-route from England to the Cape in point of speed. Its object is commercial. Like a gigantic backbone, it will carry the nerves of commercial life along the continent, promote local traffic, and by means of branches to the oceans on east and west, furnish outlets for the great future trade of Africa's wealthiest regions—the central.

Until a railway comes it is impossible to judge the capabilities of those tropical countries round the great lakes. But let the iron way pass through, and then what wealth of cattle, grain, rubber, cotton, sugar, spices, and minerals of all sorts may reward the capitalist who has risked his money! Africa is a country to be conquered by the railway. Already the Uganda line—of which more presently—has dealt deadly blows to the slave traffic, and given us such a grip on the country as nothing else, not even the constant incursions of disciplined troops, could give. The same story will soon be told of the Cape to Cairo line.

The first stage of the scheme was completed long before Mr. Rhodes had touched it with the magic of his name. In 1859—Mr. Rhodes was then six years old—a line was begun between Cape Town and Well-

ington, 58 miles away. The discovery of diamonds in Griqualand West, 1867, caused a sudden extension to Worcester, through very difficult country, where heavy gradients and sharp curves are the rule. The terminal station quickly changed its name, Matjesfontein, Kimberley, Vryburg, as the rail passed over the rolling Karoo. In 1885 the first train steamed into Kimberley; in 1890 Vryburg stabled the iron steed.

Mr. Rhodes now came in. In 1893 the Rhodesia Railways Company was formed for driving a line through Mafeking to the Zambesi. The British South Africa Company advanced the money, and Messrs. Pauling & Co. undertook the contract, with Sir Charles Metcalfe and Sir Douglas Fox as engineers. The going is easy through Bechuanaland, and consequently railhead advanced very fast. By June 1895 Gaberones was reached. On November 4, 1897, a decorated locomotive slid into Bulawayo, 1360 miles from Cape Town.

The engineers have not halted there. To the north-east the line stretches a farther 250 miles to Salisbury, where it joins the track running south-east to Beira on the Portuguese coast. Another track runs north-west from Bulawayo to the Wankie Coal Fields *en route* to the magnificent Victoria Falls. As Cecil Rhodes wished it, the spray of the Falls will soon pass over the carriages. From the Zambesi the rail is destined to pass through North-Eastern Rhodesia, rich in minerals and rubber, to the southern end of Lake Tanganyika.

From this point the route is a matter of discussion. Some people urge making use of the string of great lakes, Tanganyika, Kivu, Albert Edward Nyanza, the Albert Nyanza, joining them by short lines, and so attaining the Nile, which would float the traveller and his merchandise down to Khartoum, where he may take his choice of river or rail.

Major-General Sir Rudolf von Slatin, an authority worth quoting, is entirely in favour of utilising the Nile waterway between Khartoum and Uganda. "With reference to the Cape to Cairo railway," he says, "in my opinion it will be quite useless, and only a waste of money, to continue the railway south from Khartoum. . . . From Khartoum to Uganda is practically impossible for a railway without the expenditure of immense capital, and in any case during the rains there would be so many interruptions that a line would be practically useless. As you have a waterway in this direction and a river navigable the whole year, it would seem a waste of time and money to build a railway which could never be relied on."

As the line will serve commercial purposes, it is therefore probable that for many years it will terminate at or near the Albert Nyanza.

About the middle section—*i.e.* from the south end of Tanganyika to Albert Nyanza—Mr. E. S. Grogan, the first white man to traverse Africa from south to north, has made the following suggestions.

To utilise Tanganyika from Kituta to Usambara near the north end. From that point a light railway

could be laid along the flat valley of the river Rusisi to the south end of Lake Kivu. Then steamer again for 60 miles to the north-east corner of the lake, whence another short line would pass through the mountains, and drop gradually to Lake Albert Edward, which it would skirt on the right bank, until the main stream of the Nile is reached. Except in the neighbourhood of Mount Ruwenzori the country does not afford any great physical obstacles to the engineers, whose deadliest foe probably would be the fevers that breed so freely in the swamps of Central Africa.

The first feeders of the main line will, on account of geographical conditions, run in from the east coast. Already we have the Durban-Pretoria and Delagoa-Bay-Pretoria railways stretching towards the backbone. Farther north is the Beira-Salisbury connection. North of that again is projected a German line from Dar es Salaam to Ujiji on Tanganyika, with a branch to the Victoria Nyanza, to which English engineers have driven the now famous Uganda Railway. A short track from Berber to Suakin would place the Cape-to-Cairo in communication with the Red Sea.

The Uganda Railway, running from the island of Mombasa to Port Florence on the Victoria Nyanza, is 580 miles long—that is, it covers a distance 50 miles greater than the journey from London to Aberdeen.

Surveys for the line were begun in 1891 and completed by 1895. The following year operations commenced at Mombasa, which was connected with

the mainland by a temporary bridge while the fine Salisbury Bridge was in course of construction.

The road passes through hilly country that rises steadily for the first 360 miles, with occasional dips, to an elevation of 7800 feet. It then sinks nearly 2000 feet into the Great Rift Valley, preparatory to a precipitous climb to Mau, 8300 feet above sea-level. Then follows a continuous drop of 4500 feet to the lake.

The engineers were much troubled with labour questions. The country is sparsely inhabited, and the natives are among the laziest folk on the earth. Mr. Grogan says in this connection : "The natives of the country, alas ! were skin and bone. A two years' drought had driven them through starvation to death by the thousand. I saw grown men and women scrambling for grains of rice that had accumulated on the filthy ground sheets or bare floor of the Indians' tents, and women carrying huge planks by a strap round the forehead in order to earn a handful of food from the two hulking coolies whose work it was . . . all because you can't get a day's work out of an African buck nigger even though he be starving." [1]

As a result Indians had to be imported in large numbers. An army of 20,000 workers had to be fed, provided with water in an almost waterless country, and protected by stockades against man-eating lions which committed severe depredations among the

[1] "From the Cape to Cairo," p. 198.

working parties. The presence of the dreaded *tsetse* fly, fatal to cattle and beasts of burden, necessitated the transport of material from railhead to advanced parties on men's backs—a very laborious and tedious process. Add to this the prevalence of fevers, "jiggers," ulcers, and sores resulting from contact with the poisonous thornbush through which the pioneers had to cut their way for miles at a stretch, and risings and rebellions among the natives.

There is but one tunnel on the line, at a point about 50 miles from the lake terminus. But there are many bridges, some half a mile long and over 100 feet high. Gradients are heavy, especially in the Rift Valley, where some very clever engineering has carried the rail down the precipitous escarpment.

The chief stations are Mombasa, Kilindini, Voi (100 miles from Mombasa), Makindo (205), Nyrobi (345), and Nakuro (450). Nyrobi is the headquarters of the line, with workshops, engine-sheds, and administrative offices.

On December 19, 1901, the first locomotive reached the lake, which is now 2½ days' journey from the coast. Over the old caravan route the time was 70 days. The railway, which is of metre gauge, laid on iron and wooden sleepers, cost the Government £5,206,000. In 1901 the rolling stock included 69 locomotives, 150 passenger cars, and 850 goods waggons.

Now that the road is completed, a great opening up of trade may be expected. Two steamers of 600 tons

displacement are being conveyed in pieces to the lake, where they will be assembled, and initiate a regular service. The Victoria Nyanza, with its 500 odd miles of coastline, taps a huge area, the trade of which will naturally gravitate to the Uganda Railway, and make it, as first in the field, the established trade route. It is therefore expected that after the year 1910 the railway will begin to give substantial returns in addition to paying its own way. Of its beneficial effect on the country there can be no possible doubt. Sir Harry Johnstone has instanced as a tangible proof of the pacific influence of the iron way, the fact that the erstwhile cattle-raiding, man-hunting Masai has consented to lay aside his murderous assegai for the navvy's pick.

The southern section (Cape to Bulawayo) is extremely up-to-date. After what we have read of railway travelling in South Africa during the late war, we may be inclined to regard it as a thing to be avoided. In cattle trucks it is so, no doubt. But if you choose to lay down fifteen guineas on the counter, you may travel from Cape Town to Bulawayo in a train that will compare favourably with anything to be found in England or on the Continent. The *train de luxe* contains dining and sleeping cars, lounges, kitchens, pantries, lavatories, and bathrooms; in fact, all the conveniences of modern life.

Already an arrangement has been made with the Cape Government Railways under which circular tourist tickets, available for one month, will be issued

By permission of the] [*British South Africa Company.*

A Typical Clearing for the Trans-Continental Telegraph Line between Cape Town and Ujiji, on Lake Tanganyika.

For hundreds of miles the engineers had to force their way through primeval forest.

[*To face p.* 174.

for all stations on the Cape and Rhodesian railways. When the tourist begins to be considered, a country is pretty well advanced. The sportsman, too, will be provided for. He will be able to hire saloon carriages by the month, and travel whithersoever he wishes on the South African railway systems, keeping the saloon on a siding to act as headquarters for a shooting trip. For the sightseer the great magnet will be the Victoria Falls, eclipsing Niagara in their grandeur. The water-power running to waste will be harnessed in part before many years are out, and then we may expect to see an industrial town rising on the banks of the Zambesi, in which will be treated the copper, lead, zinc, and iron known to exist in vast deposits in Central Rhodesia. "Victoria Falls" will thus become one of the great stations on the Cape-to-Cairo line, and the centre of a civilisation eclipsing that which has left behind it many imposing ruins at Zambybwe and elsewhere.

Side by side with the railway, but not entirely on the same route, another gigantic enterprise is being steadily pushed forward—the Trans-Continental Telegraph. Work of this kind is not heralded by such a flourish of trumpets as is blown over plate-laying, but its difficulties are often comparable and, in many cases, even greater.

Here again the genius of Cecil Rhodes has been the mainspring of action. He obtained the necessary permission from the German authorities to push the slim wire through their territory. The price was

heavy—a separate line at his own cost between Rhodesia and British East Africa, to be owned and used exclusively by the German Government.

The Rhodes section of the telegraph extends from Bulawayo to Ujiji on Lake Tanganyika, the present terminus. The following particulars of this great scheme have been kindly supplied to the writer by Mr. J. F. Jones, Joint Manager and Secretary of the British South Africa Company.

At the annual meeting of the shareholders of the British South Africa Company in November 1892, Mr. Rhodes propounded his scheme for the construction of a telegraph line to Egypt, and asked for assistance to enable him to extend the Company's existing line from its terminus at Salisbury to Zomba in Nyassaland, and thence *viâ* the Lakes Nyassa and Tanganyika, the ultimate object being to connect with the terminus of the Egyptian Government system of telegraphs, thus placing Cape Town in through communication with Cairo and thence to England. Steps were at once taken towards the accomplishment of this design, and the African Trans-Continental Company, Limited, was incorporated on December 27, 1892.

It was decided to build the Zomba-Salisbury portion from both ends simultaneously, meeting at Tete in Portuguese territory. The Mashona rising of 1896 stopped the work on the Salisbury-Tete section, and when the country was pacified, it was found that the line had been practically destroyed. Mr. Rhodes,

therefore decided to abandon the old route, and a much better and healthier one was discovered to Tete from Umtali (on the Salisbury-Beira line), passing over the high plateau of North-East Mashonaland. Whilst this line was being constructed the line north of Tete was steadily progressing towards Abercorn at the southern end of Lake Tanganyika, which was reached at the end of 1899.

It was found that the most practicable route thence to the head of the lakes was on the eastern shore in German East Africa, and an agreement (referred to above) was entered into between Mr. Rhodes and the German Government, dated March 15, 1899, by which the African Trans-Continental Telegraph Company was permitted to construct the line through German territory.

Notwithstanding the difficult nature of the country to be traversed, the great scarcity of labour, and in many parts of water, the work was proceeded with as fast as possible, and during the month of September 1900, the line from Abercorn to Kituta (at the south end of Lake Tanganyika) was constructed and opened, and in the same month the construction from Kituta into German territory was commenced, the first German telegraph office being opened at Kasanga (now called Bismarkburg), a distance of 22½ miles from Kituta.

The extension of the line has been continued to Ujiji, a distance of 300 miles from Bismarkburg. Beyond this point construction is for the moment

suspended, awaiting developments in the Marconi system of wireless telegraphy, which it may be expedient to adopt for certain portions of the route between Ujiji and Entebbe, owing to the very great constructional difficulties presented by the nature of the country lying to the north and east of Ujiji.

In July 1898 the British South Africa Company took over the maintenance and working of the African Trans-Continental Telegraph Line, under an agreement with the Company, and the whole line is now under the supervision of the Postmaster-General of South Rhodesia.

It is possible to send telegrams to any point within Rhodesia at the rate of 1d. a word; to the Cape Colony, Natal, and Transvaal for 2d. a word; to European countries at 2s. 8d. a word.

At present 4000 out of the 5600 miles between the Cape and Cairo have been covered by the wire. Of the difficulties encountered, Mr. E. S. Grogan says—

"The work of construction (he is here speaking particularly of the west coast of Lake Nyassa), has been attended with the greatest possible difficulties from the precipitous and densely wooded nature of the country, and the pestilential climate. These had, however, by superhuman efforts been overcome in the stipulated time by the handful of men engaged on the work. A wide track, straight as an arrow, up hill, down dale, across abyssmal chasms, and through swamps, had been cleared, and iron posts set in iron shoes supported the wire. No one at home can realise the

stupendous difficulties that have been overcome. But I from observation know, and take off my hat in awed admiration of that gallant band who, quietly, relentlessly, and without a murmur, have accomplished the seemingly impossible. It stands out in bold relief as a colossal monument of what the Anglo-Saxon can do."[1]

The general routine of construction was to send ahead of the main body a small party of surveyors to decide the path of the wires. Behind them, at a distance of anything up to 200 miles, followed an army of natives, marshalled by English engineers, who cut a broad path through jungle and forest, in the centre of which the posts are placed. Each pole is 20 feet long and in two sections, the top, of wrought iron, 15 feet 4 inches, gradually tapering, the lower a cast-iron driving base, 5 feet long, into which the top section fits. The poles are fixed in the ground by means of an iron plate and spike, and steadied by stay wires. It would, of course, be useless to employ wood or any material not impervious to the attacks of the white ant. The transport of the poles, which weigh 160 lbs. each, was a most difficult matter. Along with wire and other material they were shipped up the rivers in shallow draught boats to the farthest available point, and then carried by porters or beasts of burden to the scene of operations. In connection with the Tanganyika section, vessels were built in England and transferred to the lake in pieces, re-assembled, and loaded with

[1] "The Cape to Cairo," p. 72.

material to accompany the march of the pioneers on the neighbouring shore.

In spite of the breadth of the clearings the rate of vegetable growth requires constant vigilance on the part of the line-tenders to prevent "short circuits." A regular system of patrolling has to be employed to combat the rank vegetation. In the section from Chiromo to Chikwawa on the Shiré River, through the track of swampy ground known as the "Elephant's Marsh," it is practically impossible to keep the grass in order, owing to the number of crocodiles with which the swamp is infested. The result is a great loss of current.

Elephants cause considerable trouble by selecting the poles as their rubbing-posts. When a 4-ton animal leans against a frail iron post and begins to sway backwards and forwards, something is bound to go in spite of the wire stays. The line is now so well guarded, however, that any failure is quickly remedied.

Curiously enough, very little annoyance has been given by the natives. At first, indeed, some of the tribes were inclined to pull down the wires, but a few powerful electric shocks inspired them with due respect for the iron thread, which has now become "fetish," even in districts where wire is the chief form of currency, and therefore an object of general desire.

One of the most serious blows to the expedition was the appearance of smallpox, which rages with great severity among the blacks. Panic-stricken, the

porters threw down their loads by the wayside and made for the bush in hundreds.

The rate of construction varied greatly according to the nature of the country. In some parts the line advanced 20 miles a week, but in others, especially along the shore of Lake Nyassa, where the engineers encountered a series of marshes and dense forests, progress was very slow. In the same region, owing to the mountainous character of the country, abnormally long lengths of wire have to be used to span the deep ravines.

For the present, construction is at a standstill. Whether the wires will continue their northward march to meet the Egyptian line depends on the success of Mr. Marconi's system. The distance to be traversed is great—1600 miles—and to flash messages plant of great power will be required, the maintenance of which may prove somewhat troublesome in the heart of Africa. Were Mr. Rhodes alive he would doubtless urge an all-metal connection for political reasons; just as he championed an unbroken railway track from Cairo to the Cape. The English are essentially a practical nation, and both these great schemes will certainly be completed in the most practical manner, leaving sentiment on one side.

CHAPTER IX

THE LOFTIEST RAILWAY IN THE WORLD

"CHANGE here for Mont Blanc!"

What a ridiculous thing, the reader will say, to talk of a railway journey to *the* summit of Europe. Well, Mont Blanc is inviolate at present; it is still a feat to reach the snowy top, and to win a head guide's diploma to show that you have attained the mountaineer's desire.

But engineers are very persistent, and, acting on the principle that where man can make a path he can make a railway, have attacked Snowdon, and the Righi, and Pilatus, and the Jungfrau herself. It seems a daring thing to attempt a steel track to the topmost peak of one of the loftiest Alps, over which the tourist shall roll in comfort to altitudes hitherto attainable only by sweat of brow and the exercise of iron nerves.

The days are fast passing when the ascent of the Jungfrau will be considered an achievement. For electric drills are busy at work in the mountain side scooping out a tunnel through the calcareous rock. The Jungfrau line, starting from Scheidegg, will bore its devious way upwards for 8 miles, until a point 200 feet below the summit is reached. The track

will be almost entirely in tunnel. The motive force, electricity, is derived from two stations at Lauterbrunnen and Grindelwald, where water turbines, driven by mountain streams, yield an aggregate of nearly 5000 horse-power. Urged by powerful currents the cars will slowly climb, unseen, to the limit platform, 14,000 feet above sea level. An electric lift will transport the tourist to the very summit, which commands one of the finest views in the world, including the Finsteraarhorn, the Weisshorn, Monte Rosa, &c. That science may wait upon pleasure, an observatory will be erected for meteorological ends on the crest of the Jungfrau.

This is the latter-day style of mountaineering. The Mark Twain or Tartarin of another generation will be mainly occupied in chronicling a series of railway journeys.

How many people know where to look for the highest railway in the world ?

Not in Switzerland, nor in the Himalayas, where the Sibi and Darjeeling lines push far up towards the clouds; nor in the Rockies, crossed by several marvels of engineering; nor yet in Mexico, a land of great elevations. No; go to Peru ! There you will find the loftiest lines hitherto laid by the engineer.

Peru has two chief tracks. One from Callao on the coast to Oroya on the *Montana* or eastern slope of the Andes ; a second from Mollendo on the Pacific to Lake Titicaca, throwing off a branch northwards to S. Rosa, on the road to Cuzco.

Both these lines pass right over the Andes. The former has a total length of 140 miles, the latter of 420 miles. Both are remarkable engineering feats, but if a comparison be instituted, the Oroya-Lima line easily bears off the palm. In about 100 miles it rises from sea-level to an altitude of 15,665 feet, or to about that of the summit of Mont Blanc. In a few hours the traveller is transported from tropical surroundings to the neighbourhood of eternal snow, where for a time he falls a prey to the *soroche*, or mountain sickness.

The line is the first section of a Trans-Continental route, partly by rail, partly by water over the tributaries and main stream of the Amazon. Between 1868 and 1872 the Peruvians discovered a great store of wealth in the enormous deposits of guano on the islands off the coast. Huge fortunes were made. Money was eagerly borrowed by Peru, and lent by England and other countries, the greater part of which loans were spent in a lavish, almost reckless, manner upon harbours, piers, and railways. Fancy prices were paid for work, costly piers and docks were constructed, and railways were projected and carried out through mountainous and desert regions, the plans of which might well have struck dismay into the most courageous engineers and investors.

The construction of the Oroya line was commenced in 1870 by Mr. Henry Meiggs, the well-known American railway contractor. From Callao to Oroya as the crow flies the distance is only 80 miles, but the line

Coasting by Hand-car on the Lima-Oroya Railway, Peru.

The experience of rushing 100 miles downhill at a stretch is possible on no other track.

[*To face p.* 184.

has a length of 140 miles owing to the multitudinous twistings and turnings, zigzags and toürniquets that distinguish its course.

To its highest point—the Galera Tunnel—the railway follows the river Rimac, which it crosses repeatedly. So steep and difficult is the country that in places the line runs in galleries cut in the face of precipices by men lowered from above in "boatswain's chairs," sailors proving especially useful.

The rail crawls up the side of most awful chasms, every now and then plunging into the rocks, to emerge perhaps on to a bridge that spans the foaming Rimac, roaring seaward hundreds of feet below. Two of the most notable crossings are those of Verrugas and the Infernillo. The first is cleared by a bridge 575 feet long, in four spans, and is supported by iron towers, the central one of which is 252 feet in height. This viaduct, which contains 662½ tons of iron, was put together by runaway sailors accustomed to work at considerable heights. A temporary wooden staging was erected on the solid rock at each end of the viaduct, and two steel ropes were stretched across the valley between the towers. The various parts necessary for the erection of the piers were brought from Lima, hung on running tackle, and thus conveyed along the ropes to their destination. In spite of the difficult conditions under which the work had to be carried out, the total time occupied was but 48 days, a truly remarkable feat!

At the Infernillo, where the main stream breaks

through two perpendicular walls of solid rock 1500 feet high, the train crosses from wall to wall, out of the tunnel on one side into the tunnel on the other over a bridge 160 feet long, 165 feet above the seething waters.

Many were the dangers to be encountered by the engineers and workmen. The work of triangulation for locating the course of tunnels and cuttings could often only be carried on from niches cut in the rock, to which the adventuresome engineer and his instruments were swung in baskets. Not less dreaded than the slippery cliffs was the Verrugas fever, that took heavy toll of the labourers. This disease is peculiar to the neighbourhood of the Verrugas stream, from which it gets its name. The patient is covered with large disfiguring warts, and often afflicted with them internally, in which case they usually prove fatal. It was reported that in one cutting alone no fewer than 700 died from this loathsome fever.

The difficulty of getting material up to the railhead may be imagined. Roads there were none, except such as were specially cut out of the solid rock for the passage of mules. Frequently a détour of miles had to be made to reach a point but a few yards farther along the course of the railway.

But in spite of almost incredible difficulties the engineers pushed on among the rocky fastnesses to the summit of the pass at Galera, whence the track falls away gradually to the terminus at Oroya.

Travellers who have journeyed on this remarkable

line, and made friends with the engineers to the extent of securing a "coast" on a hand-car from Galera to the terminus at Callao, are one and all enthusiastic over their experience. Most of us have known the delights of flying down a hill on a cycle; or perhaps we have tasted the more sudden joys of a switchback or water-chute at the Exhibitions.

But a hundred-mile coast, unbroken, over steel rails, among most terrific precipices, through yawning tunnels, over giddy bridges at a speed that severely tries the nerves of the novice until he settles down to a fatalistic apathy, or, catching the infection of rapid motion, suggests a higher speed!

Mr. Gallenga, in his interesting book on South America, thus describes his sensations:—

"The hand-car, a light, small, and low railway truck, with two low-backed seats, and room for two in each, moving with the ease of a chariot in the so-called "Montagnes-Russes," upon a gentle push from behind acquires, after a few yards' slope, a momentum of which it would be awful to foretell the consequences were it not for the breaks with which it is supplied like an engine, and by which the driver has power to pull up in a few seconds, and within a few yards of any point he may reach in his headlong career. But the driver himself, being human, delights in that entrancing rapidity of motion, and is soon almost unconsciously swayed by the fiery instincts of a racing horse. Away you go along this curve, away you tear round that corner, away you

rush and dash from turning to turning, through this cutting and that tunnel, with your face barely one foot from the hard jagged rocks of the cutting on your right, and your knees barely one foot from the brink of the dizzy precipice on your left; down you plunge into the pitch-dark tunnel, yourself without a light, without a "cow-catcher," without a bell or whistle to scare away the stray cattle that often run to it for shelter; away you go, neck or nothing, till all your terrors are shaken from you, and you become a convert to the 'perfect safety' doctrine, or till, with a fatalist's sullen courage, you set your teeth hard, you fold your arms on your breast, and almost urge the driver to more speed, as if thinking that, if there is to be a smash, it may just as well be now as by-and-by."

There are of course dangers in such a headlong rush. The curves are very sharp, and the inside rail is not sufficiently depressed to resist more than a certain amount of centrifugal force. Also rocks and stones often fall into the track, and at the sudden turns it is almost impossible to see an object a few yards ahead before the car has reached it. The ubiquitous dog, too, is found in the Andes, with its everlasting antipathy to things of swift motion; sometimes he carries his hostility too far, and there is a collision—well if nothing serious results to anything except the dog.

"This Oroya Railway is a very wonderful line indeed. It not only climbs higher than any other

railway in the world, but . . . provides the only road in the world down which a man on wheels can travel for over one hundred miles by his own momentum, and practically at any pace to which the fiend of recklessness may urge him. . . . You start under the eye of the eternal snows, and you finish among humming birds and palms. You start sick with the unspeakable sickness of *soroche*, and you finish in the ecstasy of an exultation too great for words."[1]

On the Darjeeling railway the would-be scorcher may experience the same delights for a more limited period, and on the great divide of the Trans-American lines.

[1] Lord Ernest Hamilton in *Pearson's Magazine*.

CHAPTER X

CITY RAILWAYS

AMONG the problems that perplex the civic authorities of the world's great cities, none is more difficult of solution than that which arises from the increasing congestion of traffic in the main thoroughfares.

In every large town vehicular traffic is confined to a comparatively few routes. As the town grows, the streets, which do not expand their width in proportion, become less and less adequate to pass the thousands of vehicles that crowd into them.

Nowhere has the congestion become more serious than in London, where the sight of huge strings of omnibuses, cabs, and carts, brought to a standstill by a "block," is too common to cause much comment. Travel through London streets is notoriously slow, and the delay, besides being vexatious to the individual, has been calculated to cost the community several million pounds sterling per annum. The difficulty of moving swiftly from point to point has a further bad influence as being productive of overcrowding, since the poorer classes of workers are prevented from living at a reasonable distance from the scene of their daily toil.

Patent as are the needs for freer communication

between the centre and suburbs of large cities, the means of meeting them are restricted. Old towns, where the congestion is most acute, are often cursed with narrow streets, the widening of which would be ruinously expensive. Electric trams, by monopolising the roadway would, in many cases, practically block all other vehicular traffic, and cause great inconvenience until such time as competition in fares has driven other public vehicles off the road.

It also happens that in great commercial centres, such as London and New York, a large area is given up almost exclusively to offices, which at night are deserted, but must be filled rapidly each morning, and emptied as rapidly in the evening. Thus, to take the City of London proper, although but a square mile in area, with a day population of about 300,000, and a night population of perhaps 30,000, in a single day more than 1,250,000 persons and 100,000 vehicles enter and leave the limits.

Vehicular traffic on the surface can be eased only by providing more or wider streets, or by removing the necessity for the existence of a large proportion of the vehicles. The object of modern systems of communication is to replace the thousands of independent vehicles that block our streets by some ordered arrangement of transport, running at regular intervals on its private tracks, out of the way of ordinary traffic.

Two main methods may be distinguished: the elevated railway, which is carried aloft *over* the streets,

and the subterranean railway that runs *under* the streets. In both cases the prime object is to keep as near the main routes as possible.

The States are the home of the Elevated Railway. The first was built in New York in 1870 on a single row of columns. By 1878 there were four such lines, parallel, in New York; and since that date similar tracks have been laid in Boston, Chicago, Berlin, and Liverpool. Railways of this type are especially suitable where the traffic is light and the construction of the line does not injure neighbouring property.

For really heavy traffic, or where a line must be built at any cost, the engineer resorts to the underground railway.

This may take one of three forms. It may be just under the street, separated from surface traffic by but a foot or two of steel girders and cement, as in the Buda-Pesth and New York Rapid Transit Railways. The latter has four tracks abreast in as many tunnels, the inner pair for fast, the outer pair for local, traffic. These lines, as easily accessible from the street, are very convenient when made; but their construction entails the pulling up of the roadway, the displacement of water, gas, and sewerage pipes, with all the attendant drawbacks.

The second type is illustrated by the London Metropolitan and District Railways, constructed by "cut and cover," and shallow tunnels at such a depth (30 to 40 feet below the road level) as to obviate the

necessity of lifts, though deep enough to be inconvenient.

The third and most modern type is the electrically worked deep level "tube," driven 40 to 120 feet below the roadway. Such a line is economical to build, as it entails no interference with existing structures, but has the disadvantages arising from the constant employment of lifts for the transport of passengers to and from the surface.

For London needs, however, the tube is particularly suitable. The "Inner Circle," completed in 1884, is most useful as furnishing a connecting link between most of the London termini of the great lines. But for the "City man" hastening to business it leaves much to be desired, since it skirts the area in which his business lies, and often drives him eventually to the cab or omnibus.

London's crying need is for radial lines, to intersect the area enclosed by the Inner Circle from east to west and north to south, and extend into the suburbs.

Already three "tubes" are in operation—the Central London, from Shepherd's Bush to the Bank; the Waterloo and City; and the Stockwell-Monument. Others are in course of construction, from Baker Street *viâ* Charing Cross to Waterloo, and from the City to Finsbury. In addition, powers have been granted for new railways between Brompton and Piccadilly; Charing Cross, Euston, and Hampstead; Brixton and the City; the Marble Arch and Cricklewood. A few years hence there is every prospect of

the clay on which London stands being honeycombed by "tubes."

From the tube to the *teredo* or ship-worm is a far cry, yet there is an interesting connection between them. Sir Isambard Brunel, the famous builder of the first Thames Tunnel, employed a shield to pierce the soft ground under the river. It is said that he derived his idea of a shield from observation of the ship-worm, which digs its way into wood by means of a boring apparatus in its head, and as it advances lines the hole behind it with a secretion thrown out from its body. Taking the hint from Nature he patented in 1818 a device, consisting of an iron cylinder furnished at its front end with an augur-like cutter. As the cylinder advanced the hole behind was to be lined with a spiral sheet-iron plating, faced on the interior with masonry.

Brunel's crude idea has been immensely improved upon by himself, Mr. Peter W. Barlow, and Mr. J. H. Greathead, who has given his name to the shield employed on the London tubes.

The Greathead shield consists of three parts, the front, the body, and the tail. The shield is perfectly circular and cylindrical, and is built up of steel plates riveted together with countersunk rivets so as to give an absolutely smooth surface on the outside. To stiffen the cylinder a diaphragm or bulkhead, in which is cut a hole for working through, is fixed transversely. The front end extends forward from the diaphragm to the cutting-edge, which is formed of a strong cast-

iron ring divided in halves, on which are secured steel knives made in short segments and forming a true circular cutting-edge. The knives are arranged in such a manner that if necessary they can be adjusted to cut a hole slightly larger than the shield.

At the back of the bulkhead comes the body, in which are located the jacks, pumps, and motors for manipulating the shield. At the back end is a powerful cast-iron ring, to which are attached, at regular intervals round the circumference, the hydraulic rams for forcing the shield forward. The united power of these hydraulic jacks is immense, as even in stiff and stable clays, where the friction is at a minimum, a pressure of 4 or 5 tons for every square yard of the external surface of the shield is required, and in sticky material the power must be increased to 18 or 24 tons per square yard of exterior shell. Each jack can be used independently of the rest, and by suitable combinations the course of the shield is steered to a nicety.

The tail of the shield serves to support the earth while the lining is being placed. For this reason its diameter is such as just to clear the outside of the lining, which is added inside it.

The details of the shield vary with the nature of the stratum penetrated. In very stable material, where caving and water inroads are unlikely, the diaphragm may be omitted; while in treacherous water-logged materials, such as were encountered in the bed of the Mersey (see page 73) and Thames during the driving

of the Waterloo-Baker Street tunnels, means must be provided for closing the shield entirely and converting the front end into an air-tight chamber accessible through air-locks.

After this short description of the boring apparatus, we will turn our attention to the sphere of its operations.

The City and South London Railway, extending under the Thames from the Monument to Stockwell, a distance of 3½ miles, was begun in 1886 by Greathead. Its promoters originally intended to operate it by an endless cable, but during its construction electric traction developed sufficiently to be applied to this first of tube railways. The tunnels, running parallel, are 10 feet 2 inches in diameter.

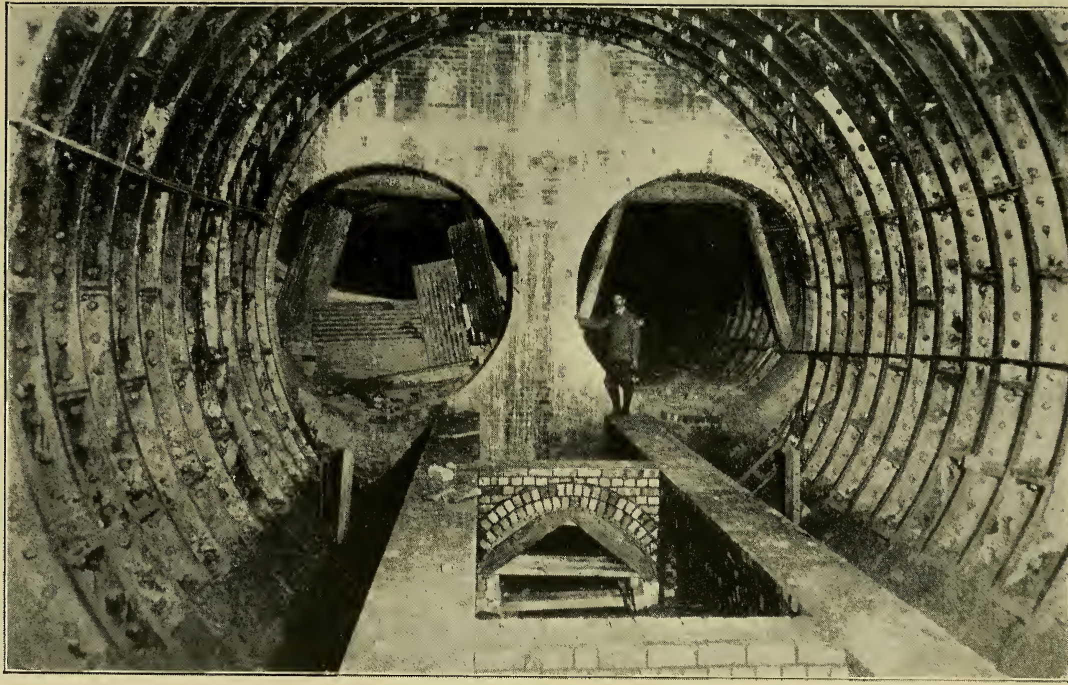
The Waterloo-City tube was next constructed, and in 1896 the engineers commenced the most important of the lines at present open, the Central London Railway.

The construction of the "tube" is very unostentatious and attracts little attention. All the public sees is a series of enclosures surrounded with hoardings, in and out of which carts pass laden with earth or strangely-shaped masses of iron. A steam crane or two tells of work in progress, but there is little for the inquisitive passer-by to watch.

The scene of active operations is far down below his feet, where shields are steadily eating their way through the stiff London clay.

Excavation proceeds[1] from several points simul-

[1] The Central London Railway is taken as typical.



From a photo lent by] [*Sir Benjamin Baker.*

At Shepherd's Bush Station, on the Central London Railway, showing the "Tube" in course of Construction.

The small tunnels are 11 ft. 6 in. in diameter, the large about 26 feet.

[*To face p.* 196.

taneously. At the site of each station a shaft is sunk, and lined with cast-iron segments, bolted together. As soon as the shaft is completed temporary cages are provided for bringing up the excavated material. A chamber is then cut out in which the smaller shield for driving the track tunnels is erected. Its diameter is 12 feet 8 inches. Several rings of lining, each 20 inches long, are placed, and the shield adjusted so that its six rams get a push-off from the most advanced of them. Water power is then applied, and the shield moves forward through the clay which has been partially removed in advance. Taps are turned on, and the rams retire into their cylinders, making way for the next ring, which in turn takes the pressure off the rams. The annular space left outside the lining by the tail of the shield is now filled in with liquid cement, squirted through holes in the lining under pneumatic pressure. The rate of progress varies from two to four rings every ten-hour shift.

For removing the clay an ingenious form of electric excavator was used on several sections of the tunnelling. The machine is a dredger ladder, the working end of which can be moved vertically, horizontally, and longitudinally. Thirty-seven buckets on an endless chain scrape the working face, and carry the spoil back into the small waggons that roll under the rear end of the machine. It was found that this contrivance removed so much of the face that the shield could cut away the remainder, so obviating the need of hand-picking. As soon as the men came to

thoroughly understand it, the rate of advance increased rapidly, and eventually four rings were placed in the shift. With the machine only six men were required at the face; without it, fourteen.

For clearing the stations a large shield, 22 feet 10 inches diameter, was used, driven by twenty-two hydraulic rams. The stations are 325 feet long. The iron segments are filled in with cement and lined with white glazed tiles, which materially aid the illumination of the platforms.

The tunnels as a rule run side by side, but in one or two places, *e.g.* at Newgate Street and Notting Hill Gate, where the roadway is narrow (and the line must keep under the road), the tunnels curve upwards and downwards until they pass one over the other.

The depth of the line varies considerably. At the Bank the metals lie 60 feet below the surface, at Oxford Circus 80 feet, at Notting Hill 92 feet. The engineers have arranged the stations on the summit of gradients, which assist the train to stop, and also to start. On leaving a station the tunnel drops at a gradient of 1 in 30 for 300 feet, and when approaching rises 1 in 60 for about 600 feet; so that the stations stand about 10 feet above the general level of the line.

The most difficult part of the construction was at the Bank Station, where a regular network of subways cuts the existing gas and water pipes. The station space here is entirely underground, a few feet below the surface. But the station, lift-shafts, &c., were

made without in any way disturbing the traffic overhead.

The Central London Railway was opened on July 29, 1900. It cost £3,500,000. The engineers were Sir John Fowler, Sir Benjamin Baker, and Mr Basil Mott. The need for its construction is proved by the passenger returns, which in 1901 showed 41,188,389 tickets taken. Two objections have been raised to the "Tube"—the vibration, which seriously annoys the occupants of houses on the route, and bad ventilation. The first could be largely removed by the employment of what is known as the multiple-unit system of traction, in which every car or group of two cars is furnished with its own motors, and may be cut off from the rest of the train. The displacement of the heavy pounding locomotive by motors distributed among the cars will not only lessen the vibration, but render the handling of traffic much more elastic. Trains can be lengthened or shortened according to the varying requirements of traffic at different times of day. In America the multiple-unit system is generally used on about 3000 cars, aggregating 375,000 horse power. Mr. Frank J. Sprague, whose name is so well known in connection with electrically operated rails, says :[1]—

"The ideal service, so far as the passenger alone is concerned, would be by single cars operated at high speeds, and following each other at the shortest pos-

[1] *The Engineering Magazine*, October 1901.

sible intervals. The conditions of tunnel service, however, and the heavy character of the traffic at certain hours prohibit this ideal condition. So there must be, to get the most practical results, an expansion of the car into a train varying in length according to the time of day, and a lengthening of intervals to meet the requirements of operation at high speed. . . . Such a system readily lends itself to every condition of congested service. The similarity of equipment insures flexibility of train operation, and provides a motive power proportioned to the requirements."

Briefly put, "one car one motor" appears, as a principle, better adapted to the requirements of rapid travel between frequent stations than, "one train one locomotive." Two main steam lines, the North-Eastern and South-Western, have recognised the expediency, and placed single motor-coaches on their metals to run at short intervals between the regular train service. In course of time we shall see the Metropolitan and District Railway electrified, and also some of the suburban lines. In fact, it is not over bold to prophesy that the competition of tubes and trams will drive all local and suburban lines to the electric current, with its far greater range of train load than is possible economically with the steam locomotive. To quote Mr. Sprague again: "The electric railway has become a modern necessity, and the greatest of philanthropic agents. It is a distributor of the masses, and the most effective agent in solving the housing problems of the metropolis.

Every minute taken from the time of transit to and from business is a minute added to the fireside and home. Every increase of speed adds to available dwelling space, increases taxable areas, augments traffic, and betters the *morale* of the people. The days of doubt and hesitation have long passed. Within thirteen years, in the United States alone, electricity has been adopted on more miles of street, elevated and suburban track, replacing horse, cable, and steam equipments, than there are miles of steam railway in Great Britain. It needs but a practical survey of all that has been accomplished in this connection to realise the immense benefits possible by an intelligent adoption of electric propulsion."

The Baker Street-Waterloo line, in course of construction, will be of an importance second only to that of the Central London, as it affords the much-needed link from north to south along the route between Regent's Park and Charing Cross, which is at present served only by omnibuses. The extension to the south side of the Thames will also prove most convenient. This line, which commences at Baker Street, where it picks up passengers from the St. John's Wood branch, passes along the north side of the Metropolitan to the north end of Portland Place, under which it runs to Oxford Circus. Here passengers will change on to the Central London. The line then follows Regent Street to Piccadilly Circus, and doubles down the Haymarket to the east side of Trafalgar Square, passing close to Nelson's Column;

then under Northumberland Avenue to the Thames, beneath which it passes a little west of Charing Cross Bridge. As an engineering feat, this line has proved more difficult than the Central London, on account of the several curves and the passage of the Thames.

The first constructional work on the line was conducted from a stage built on the north of the Thames. Two vertical shafts were sunk into the bed, and from them parallel tunnels driven to meet borings working southwards from Piccadilly Circus. In spite of the curvature of the route, the tunnels met so accurately that an error could scarcely be detected. The frequency with which this feat is performed shows that tunnel-ranging has become a very exact science. As on the Central London, the gauge is standard, viz. 4 feet 8½ inches, and the tunnels have an equal diameter, 11 feet 6 inches. It is expected that the line will be opened for regular traffic in 1904. Eventually it will extend to Bishop's Road, Paddington, and so place the Great Western Railway in direct communication with the South-Western *viâ* the West End.

Future tube railways will have a larger diameter than that of the existing systems. Expert opinion suggests 13½ feet as affording better ventilation, facilitating repairs, and minimising the effects of an accident. The Great Northern and City tube is 16 feet in diameter, to accommodate the steam railways' ordinary rolling stock. It may be regretted that this size was not adopted as the standard for all the tubes.

If the various companies will only work in partnership and organise the various systems into an harmonious whole, London should in a few years' time be one of the best served cities in the world.

CHAPTER XI

THE SEVERN TUNNEL

"The Severn Tunnel, which is a little over four miles in length, is by far the most important subaqueous work yet accomplished."—Mr. J. E. Tuit in "The Tower Bridge."

In the West of England the broad Severn estuary offers a serious obstruction to traffic between South Wales and the south-west counties—Cornwall, Devon, Somerset, and Dorset. At Weston-super-Mare the channel, still several miles broad, makes a sudden turn in a north-east direction to a point some distance beyond Gloucester, thus forming a natural obstacle on the southerly flank of Wales across the main roads from the thickly-populated coal-fields of Wales to the great Metropolis. Thomas Telford, a hundred years ago, linked up the turnpike road at Gloucester by a bridge of 150 feet span, so that coaches might travel unimpeded; and in 1879 was completed an iron bridge three-quarters of a mile long, which crosses the Severn 26 miles below Gloucester, enabling the Midland line to Bristol to tap the coal-fields of the Forest of Dean, and putting the Great Western also in more direct communication with the same district.

Owing to the configuration of the country in the Stroud Valley, the branch of the Great Western that

passes through it towards Gloucester is characterised by very severe gradients and sharp curves, that detract seriously from speed while adding considerably to the cost of haulage.

To avoid this route became the policy of the enterprising Directors of the Great Western. They constructed a single line from Bristol to New Passage, a point a few miles above Portishead and the Avonmouth Docks. On the opposite bank the South Wales Railway terminated near Portskewett, a small agricultural parish. On each bank a large jetty was thrown out, and a steam-ferry supplied a means of transporting goods and passengers across the Severn. This, however, was far from satisfactory. The Severn, by presenting a funnel-shaped cul-de-sac to the strong tide running in from the Atlantic, is subjected at spring tides to a rise of 50 feet, rivalling in height that of the Bay of Fundy, and surpassing anything to be witnessed elsewhere in England or on the Continent. The strong currents resulting from the sudden rise and fall of the river produce a continual shifting of the sandbanks most prejudicial to navigation, and render the embarkation at pierheads a troublesome proceeding.

The Great Western Directors therefore thought it would be to the Company's interests to incur a further expense to avoid "breaking bulk" and transhipping passengers. The bold project was set on foot of driving a tunnel under the bed of the Severn, from New Passage to Portskewett, where the river is more

than 2 miles wide. The lowest point of the tunnel must necessarily be under the deepest part of the channel, and unfortunately that point was within a few furlongs of the Welsh bank, where the currents have eaten out a depression known as "The Shoots" to a depth of some 50 feet below the general level of the bed. So that though the New Passage end of the tunnel would be only 700 yards from the river edge, the Portskewett face would be 1¾ miles inland, in order to preserve an easy gradient of 1 in 100; and at each end it would be necessary to make large cuttings of a maximum depth of 80 to 90 feet—the tunnel itself to have a total length of 4½ miles.

In November 1871 Mr. Charles Richardson deposited plans for the tunnel in Parliament, and in the following year an Act was passed for its construction.

The Great Western Railway Company at once set to work, after obtaining the services of Sir John Hawkshaw as consulting engineer. Sir John had already gained valuable experience of tunnelling in the completion of the East London Railway from Brunel's Thames Tunnel under the London Docks through Wapping, Shadwell, and Whitechapel—a work of extreme difficulty.

A start was made in 1873 by sinking a shaft—afterwards known as the Old Shaft—15 feet in diameter and 200 feet deep, on the Monmouthshire side, and lining it with brick. From the bottom of the shaft a heading, or horizontal excavation, was made river-

wards in the line of the tunnel, to act as a drain that should tap the tunnel at its lowest point under "The Shoots." It had an upward gradient of 1 in 500, and in section was 7 feet square.

Matters progressed so slowly, however, through want of a sufficient staff, that by the latter half of 1877, or after four and a half years' work, the Company, who were carrying on the excavations, decided to ask for tenders for the completion of the whole work. Three estimates were sent in, one by Mr. T. A. Walker, who afterwards took so important a part in the construction of the tunnel. But the estimates being considered excessive, the Company decided to continue a heading right under the river, in order to ascertain the nature of the strata to be pierced before going to the contractors. Small contracts were, however, let for the sinking of one shaft on the Gloucester side, and two on the Welsh side, known as the Marsh and Hill Shafts; and for the driving of horizontal headings both ways from the bottoms of the shafts.

The Company then completed a second shaft for pumping near Old Shaft, and lined it with iron to within a few feet from the bottom, where it was connected to its neighbour by a short tunnel closed at the Iron Shaft end by a small trap-door.

On October 18, 1879, an incident took place which marked the date as a black day in the history of the tunnel. In order that the reader may understand clearly what follows, it will be necessary to

explain that 40 feet above the drain-heading running under the river from the bottom of Old Shaft, headings were being broken in both directions from the same shaft for the traffic tunnel, which at this spot would have risen some distance above its lowest point. Men were working in the western heading, when suddenly a large body of water was tapped, and after valiant, but vain, efforts to stem the tide, the excavators had to fly for their lives. The water, leaping from the heading-face a sheer 40 feet to the bottom of Old Shaft, began to fill up the long sub-river heading, and the men there would have had all means of flight cut off but for the cross tunnel to the Iron Pit, through which they escaped.

In twenty-four hours' time the whole of the workings in connection with Old Pit—that is to say, by far the largest portion of the excavations—were full to tide level, and the result of seven years' labour appeared a melancholy failure. Hitherto the general opinion had been that danger from water—that untiring, wakeful foe of the tunnel-driver—was to be apprehended while piercing the strata below the river. But inasmuch as the water that had burst in was fresh and sweet, it became evident that the engineers had to reckon with some subterranean supply fed by the neighbouring hills.

The Directors decided on drastic measures. They appointed Sir John Hawkshaw engineer-in-chief, giving him powers to place a contract with some one whom he might consider to be a fit person to carry

out the work. He selected Mr. T. A. Walker. This gentleman had already won his spurs as a railway surveyor and contractor in Canada, Russia, and Egypt; and under Sir John had completed the East London Railway extension referred to above. He now made a contract to finish the tunnel, cuttings, and approaches, a total length of 8 miles 26 chains; the tunnel to carry a double line of rails, and be 24 feet high inside from top of arch to lowest point of invert, with a maximum width of 26 feet at the spring of the arch.

In signing the agreement he entered upon an undertaking not to be matched in engineering, unless, perhaps, we except the driving of the Kilsby tunnel by Robert Stephenson. A digression for a few lines will be excusable, in order to remind the reader of Stephenson's famous feat. When the North-Western Railway was in course of construction, the promoters proposed to carry it through Nottingham. But the Nottinghamians would have none of the new-fangled iron horse, and a détour must be made through the hills near Rugby. Stephenson faced the gigantic task of cutting a tunnel 1⅓ mile long, after he had, by means of trial shafts, ascertained, as he thought, the exact nature of the strata to be encountered. A contract was let to build the tunnel for £99,000. Before work had proceeded far the unfortunate contractor ran against a large, water-logged quicksand. He died soon afterwards, heart-broken, though the Company generously waived the terms of the contract. Robert

Stephenson stepped into the breach, declaring that he was quite able to master the quicksand, by the simple, even if expensive, method of pumping it dry. The pumps threw out water ceaselessly for *nine months* at the rate of 1600 gallons a minute, but without any apparent benefit, until the patience of the Directors gave way. They said that to go on flinging good money after bad would be madness. "Give me another fortnight," replied Stephenson, "and if by the end of that time matters are as bad as ever, we must abandon the tunnel."

We may imagine the anxiety with which the work was watched. Every hour measurements were taken of the water flowing to the pumps. The end of the fortnight came perilously near, and still no improvement. How poor Stephenson must have despaired inwardly while keeping a brave front to his men! How deep must have been his feelings of gratitude and triumph when at the eleventh hour the word went round that the water was not gaining! The quicksand was almost dry, the tunnel was saved, and completed at a cost of £300,000.

Mr. Walker at once set about erecting pumps to battle with the Great Spring, as it came to be called, and to clear the flooded workings. Before these could be emptied it was necessary to block the heading into which the spring had broken at its opening from the Old Pit. Accordingly two shields were made of the same curvature as the shaft, sufficiently ample to cover the mouths of the headings on either

side. Unfortunately the depth of water from the surface to the headings—140 feet—produced so great a pressure that divers could not work in it, and it became necessary to lower the water 50 feet to reduce the strain. Great trouble was experienced with the pumps, which gave way first in one part of their mechanism, then in another; but in spite of these untoward incidents the shields were fixed by the 24th January 1880, and made water-tight in a few days more. The Great Spring had now been cut off, but water still leaked in at the bottom of the Iron Pit in greater quantities than the working pumps could cope with, and there was nothing to be done but wait for the arrival of additional pumps. A new 18-foot shaft was put in hand close to the Old Shaft and over the line of the tunnel, to act as a pumping-pit.

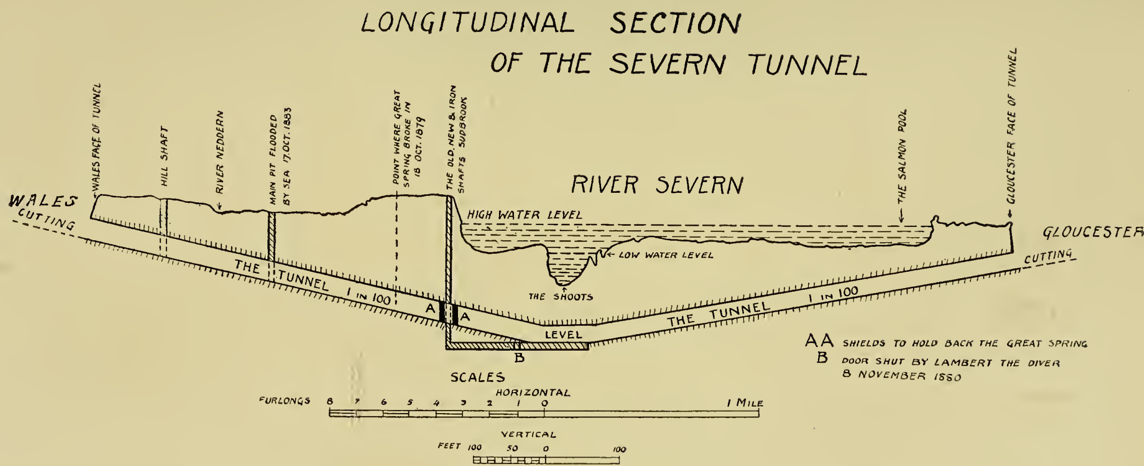
At last a long-expected pump of large capacity arrived and was fitted in the Iron Pit, which had been cleared to within a few feet of the bottom when the pump burst with terrific violence, and in an hour or two the shaft was full again. The pump was repaired and replaced by October 14. On that day, at 11 A.M., began the final struggle with the water.

In twenty-four hours the water had been lowered 121 feet, enabling a damaged pump to be repaired and brought into action. These two pumps being able to do no more than "hold" the water that came in from the long sub-river heading, Mr. Walker determined to close, if possible, a door in a head-wall that had been

built across the heading at a point 1000 feet from the bottom of Old Shaft.

The task was one for a diver, and a brave diver too. To say nothing of the 30-foot head of water giving a pressure of 13 lbs. to the square inch, he must walk up the heading, drawing 1000 feet of hose after him, go through the wall door, close the flap of one sluice, return through the door, make it fast, and screw down a 12-inch sluice in the other side of the wall. A diver named Lambert undertook the job. Three other divers accompanied him part way to help pass the air-hose, the friction of which against the roof of the heading would have been too great for his tractive powers.

He set out on his dangerous expedition armed with a short crowbar, and groped his way in darkness over the débris—skips, tools, lumps of rock—until within 100 feet of the door, when the weight of hose prevented farther progress, and he was obliged to retrace his steps. Two days afterwards Lambert made a second attempt, wearing a Fleuss dress—which replaces the air-hose connection by a cylinder of oxygen carried on the diver's back—but remained under water only half-an-hour. A third attempt was more successful; Lambert reached the door, but did not close it. The fourth trial, which lasted eighty minutes, resulted in the closing of the door and sluices. With great anxiety the floats that told the level were watched after pumping recommenced, but to the disappointment of all the subsidence amounted at the most to



Section of the Severn Tunnel.

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3 inches an hour, and at high tide to nothing at all. By the 7th December, however, the use of additional pumps had cleared the Iron Pit, and the foreman was able to reach the cross-wall to which Lambert had made his venturesome and perilous expedition. It was then discovered that the screw-down valve traversing the wall had a left-handed screw, so that Lambert, while closing it down, as he thought, was in reality opening it to its full extent. But for this mechanical vagary the work of pumping would have been a simple matter after the door was closed.

The next thing to do was to tackle the western heading into which the Great Spring had burst. The door in the shield at its pit end being opened, the engineers explored the scene of the inrush. A great quantity of matter had been washed in by the water, partially blocking the heading, and it was therefore decided to keep out the water by building a wall across the heading at a point where the ground appeared firm. This work reached completion in January 1881. For two years the Spring gave no more trouble.

The year 1881 was marked by three notable incidents. First came the great snowstorm, still notorious, that worked havoc throughout the British Isles. It cut off communication between the tunnel and the outside world, reducing the contractors to all sorts of shifts to supply their pumping-engines with steam, in the absence of a regular supply of coal from South Wales.

In May a strike broke out among the workmen, which for a few days brought the works to a complete standstill, but ended in the men returning to work as before.

A month previously the sea had found an entrance into the Gloucester sub-river heading from a shallow reach called the "Salmon Pool." Fortunately for the fate of the tunnel the long heading from the Sudbrook or Portskewett side had not quite joined that from the Gloucester bank, otherwise the water would have poured across to the bottom of Old Pit, scouring the whole of the long heading with disastrous effect. At low water Mr. Walker made a number of men join hands and wade into the Salmon Pool, until the sudden disappearance of one of them for a moment betrayed the whereabouts of the inlet. A schooner-load of clay dumped overboard at the spot checked further leakage.

The remaining months of 1881 and 1882 passed without any serious accidents to delay the work, which proceeded apace. The method employed in making the tunnel was to securely timber the headings—driven at what was to be the bottom level of the completed work—and from them to "break up" at intervals to the level of the crown of the arch. Each break-up, timbered in turn, became the end of a top heading, 6 feet high by 5 or 6 feet wide, running a few feet above the lower heading for a distance decided by the nature of the ground, technically known as a "length." The top heading finished, a

groove is cut along the top of each side wall to receive a balk 12 or more inches in diameter of the same length as the "length" itself. Vertical grooves are then cut in the sides, and into these are inserted props to support the longitudinal balks. The excavators then dig into the sides farther, and cut two more horizontal grooves rather farther from the axis of the tunnel, but lower than the first two "crown-bars." Into these a second pair of crown-bars is rolled and similarly secured by uprights; and the operation is continued until the top heading has been widened into the outline of the tunnel arch. The floor has now to be cut away, and a support provided for all the props at the ends of the crown-bars. A deep groove is therefore sunk across the heading to a point a little lower than the inferior ends of the props, and a massive beam, 12 to 15 inches square, let into it. A second set of props is then wedged between the "sills," as the cross-beams are called, and the crown bars.

The lower heading is then widened and sills fixed top and bottom, separated by tightly-jammed props; and then, the matter between the two headings being removed, a middle tier of props set between the bottom sill of the top heading and the top sill of the lower heading.

If, then, the reader imagines himself to be in a length timbered ready for masonry, he will see overhead a number of horizontal and parallel balks reaching from the highest point of the arch down each

side of the tunnel to within a few feet of the bottom. Each end of the length is shut in by two tiers of short upright beams bearing sills, and above these again rises a third fan-shaped tier of supports taking directly the weight of the crown-bars.

The invert, or concave tunnel bottom, is then bricked, and after it the two sides to the spring of the arch. It now is time to set the "centres"—semicircular wooden frames—across the arch parallel to one another at a distance of 3 or 4 feet, and line them on their inner and outer sides with stout boards. They act as a support over which the masons can lay their bricks. Sometimes the arch is built inside the crown-bars, sometimes outside them, and sometimes between them, the bars being withdrawn horizontally in turn to make room for the bricks.

As soon as a length is completed, the excavators drive top headings from each end, removing the débris and bringing in timber and lining materials through the bottom heading, which acts as a common feeder to a succession of break-ups, each of which has two "working-faces." This system enables the work to be pushed forward rapidly, as in the confined space of a tunnel only a limited number of men can be advantageously employed on one face; and a great economy of time results when heading-driving, chambering, timbering, and lining are in simultaneous progress at different points. The care exercised by foremen and miners is evident from the fact that out of the 1500 "lengths" taken out,

in only one was the timbering unequal to the strain placed upon it by the superincumbent mass.

The strata encountered were of many kinds. Starting from the Welsh bank—alluvium, sand, white sandstone, marl, conglomerate, millstone grit, coal shale, blue shale, clay shale, red sandstone, grey sandstone, marl, and gravel. In some places pick-and-shovel work was able to cope with the strata, but in many rock-drills and blasting became necessary. When a large number of break-ups were in operation the amount of material to be transported to and from the working-faces became so great that in the Gloucester half of the long heading Mr. Walker laid down a double line of rails between which worked a continuous steel rope, actuated by an engine at the top of Sea-Wall shaft. The rope, or "bond," was carried by horizontal rollers placed on the sleepers of the road a few feet apart. When the engine was started the rope travelled at a uniform speed of 2 miles an hour round a large pulley situated rather more than a mile from the foot of the shaft. Men called "hookers-on" attached full skips to the rope flanking the "up' line, or detached empty ones from the "down" line rope. At the shaft bottom the skips were placed in cages, and after being hoisted, discharged, and lowered again, returned for another load. The system works so smoothly that at times as many as 200 skips were in motion at once; and the cost was reduced to a fraction of that of the pony haulage employed at the Welsh end.

The reader must bear in mind that in the early 'eighties the engineer was not nearly so well equipped as he is to-day. Electric lighting, for instance, was still in its infancy, and not only were candles largely used in the workings of the Severn Tunnel, but those electric lamps installed give a considerable amount of trouble and only a very inadequate amount of light according to present ideas. Rock-boring machinery also was not nearly so perfect as it is to-day, and explosives not so effective. And not until 1882 was the telephone established in the works. Mr. Walker considers that on the very first day of its instalment it averted a strike, since a ganger in the cabin at one end of the wires overheard a man saying mutinous things in the other cabin, and by dismissing him prevented further mischief. The mining engineer is now able to apply electricity in many other ways that were unknown at that time. And last, but not least, the "pneumatic shield" for penetrating water-logged strata has since then become a much more efficient machine.

On the 2nd of December a curious panic seized the workmen in the long heading under the river. Mr. Walker found about 300 to 400 men at the top of the main Sudbrook shaft, all breathless and excited, some partly naked. On inquiring what was the matter, he was told that the river had broken in, but nobody appeared to be able to give any definite statement as to *where* it had burst through. There was no more water than usual in the pumping-pit, and its

colour was unchanged. Accordingly Mr. Walker and two foremen descended the shaft and found the heading perfectly dry, except for the ordinary drainage from small leaks. In several places hats, kerchiefs, waistcoats, and leggings strewed the floor of the workings—marks of a hurried flight. It afterwards turned out that some water, imprisoned by an obstruction in a heading on the Gloucester side, had, on the removal of the obstacle, flowed down the long heading and topped the edge of a shoot that carried any leakage. The men at the Welsh end, not knowing the cause of this sudden increase in the flow, acted on a miner's advice to "fly for their lives," rushing to the Sudbrook winding-shaft. "When passing through lengths of finished tunnel," says Mr. Walker,[1] "they spread out in a disorderly crowd, running perhaps 20 feet wide; then they would come to a short length between two break-ups, where there was only a 7-foot heading. Here they threw each other down, trampled upon each other, shouting and screaming; and then, to add to the disorder, the ponies in the various break-ups took the alarm and galloped down in the direction of the winding-shaft, trampling on the prostrate bodies of the men. . . . When the men reached the top of the pit, the night-shift—which would go below at two o'clock—had already received their pay, and were gathering ready to descend. It may be imagined that these men cruelly chaffed the others who had come up, as soon as it was known

[1] In his book on the tunnel.

that there was no danger below; and I have reason to think they reaped quite a harvest of neckties and other things thrown away by the others, when they went down to their work."

Thus ended an incident which, comical enough in itself, must have given the men concerned—no one more than the contractor—a very bad quarter of an hour.

Real troubles were about to occur again. At the close of May 1883 an attempt was made to open the door in the wall keeping out the Great Spring. But the débris behind rendered all efforts vain, and eventually a hole a foot in diameter had to be bored through the door with augurs; and through this hole the men tried to clear away the impediment. This method proving impracticable, a heading was driven below the blocked heading, and a break-up made to allow the water to pass that way, and permit an examination of the upper heading. The men found that the roof had fallen in for a length of 50 to 60 feet, and that there was an enormous cavity overhead. An inclined heading was therefore driven from the top heading into the cavity, and quantities of timber and other materials thrown into it to protect the bottom heading. Three new doors were then built, one in each of the three headings, as a precaution against further irruptions of water.

But the Great Spring had only been scotched. On October 10, 1883, the unwelcome news reached Mr. Walker that it was pouring into the lower heading in

a larger volume than had yet been met with. He found, on descending the shaft, a river 16 feet wide and 3 feet 6 inches deep roaring down the 40-foot drop to the bottom of the shaft. The heading door could not be closed; the pumps could not check the inflow; and in a short time the men in the long heading were making for the Welsh shore. The next day 52 feet of water stood in the works. The services of Lambert were again requisitioned, and this intrepid diver managed to close the door through which the water flowed. By November 3 the tunnel was again freed of water and the Great Spring in check.

As though the lot of the engineers and contractors had not yet been sufficiently hard, the sea next showed its malice. The shore on the Welsh side is, at the water's edge—the site of the Old, Iron, and New Shafts—considerably above the high-tide level. But farther inland there are flat, low-lying marshes—once fertile meadow land protected by a sea-wall—liable to be swept by spring tides. In the centre of the marshes the Marsh Shaft had been sunk.

On October 17, 1883, the night-shift had descended to their work in the headings opening from this shaft. It was a tempestuous night, the wind blowing south-west, and an unusually high tide was known to be due. Previously no tide had ever reached the site of the shaft, and there appeared to be no reason for anxiety. But the wind working with the tide, as it did in November 1897 on the East Coast, piled up the waters in the Severn estuary to an alarming height.

A great tidal wave, advancing in a solid wall, burst over the marshes. Some houses, belonging to a tin-plate works, were invaded by the flood to a depth of 5 or 6 feet, and the children had to be placed for safety on piled tables or shelves. The wave next attacked the pumping-station and extinguished the fires. Then, meeting the shaft, it roared down a fall of 100 feet. What must have been the feelings of the unhappy miners below! A few managed to climb the ladders and escape, but one poor fellow, when half-way up, was torn off by the violence of the water and hurled into the gulf below.

There remained eighty-three men in the shaft. As the water rose they retreated farther up the gradient, waiting for the end. Meanwhile others, at the ground level, were making desperate efforts to form a circular dam round the mouth of the shaft. Sacks, timber, and even clothing were used. Fortunately, the first fury of the tide was soon expended. The dam served its purpose, and preparations were made for going below with a small boat to explore the tunnel. At the bottom of the shaft the water had risen to within 8 feet of the tunnel crown. The men were finally rescued from the break-up in which they had taken refuge, and brought safely to the top. Had the tide been a few inches higher it is probable that not one would have survived the catastrophe.

The position of affairs was now indeed lamentable. Flooded headings, flooded cuttings, and a spring of unknown copiousness to reckon with. The clearing

of the sea water was only a matter of time, and the workings were soon emptied. But the delays, meaning extra wages, the continually recurring need for new pumps and engines to meet some fresh catastrophe, and the huge bill for fuel, had already put the contractor £100,000 out of pocket! Still he must persevere with his arduous and wearing task: the tunnel must be finished even if it ruined him.

To the Big Spring Sir John Hawkshaw and Mr. Walker now turned their earnest attention. As a preliminary to underground operations, the bed of the small river Neddern—suspected of feeding the Spring—was lined with a concrete invert for nearly 4 miles. A heading was then driven parallel to the centre line of the tunnel, but 40 feet to the north of it, so as to drain the Spring from the flank and leave the site of the tunnel dry. The plan succeeded so well that it was possible to push on the top heading towards that running from the next shaft, and on October 17 a way lay clear from one end of the tunnel to the other. The chambering out of the Spring length was, however, a difficult business, as small fissures crossed the line here and there. But at last the masons completed their work, and the tunnel lining was finished.

On September 5, 1885, a train passed through the tunnel from end to end carrying the chairman of the Great Western Railway and a party of friends. Mr. Walker shortly afterwards quitted the scene of his labours for South America, where other work awaited

him. His old enemy soon called him back. The Great Spring was giving trouble, squeezing the tunnel lining with such force that bricks flew out from their settings. In order to relieve the pressure it was decided to erect a pumping-station for permanent use. Every day water to the average amount of 24 million gallons is emptied by the pumps into the Severn, a supply sufficient, as Mr. Walker has calculated, to form annually a lake 1000 acres in extent and 30 feet deep.

The passenger whose lot it is to be plunged for some minutes into the darkness of the Severn tunnel, will, after reading these lines be able better to appreciate the magnitude of the work needed to make his swift passage a possibility. Here are a few points for him specially to ponder upon: That the construction of the tunnel occupied fourteen years, and consumed over 77 million bricks; that the water pumped out during those years represents a lake 3 miles square and 30 feet deep; that though the working was conducted from more than forty break-ups, the calculations were made so accurately that, when the sections joined, no deviation from absolute straightness in the $2\frac{3}{4}$ miles of straight tunnel could be detected by instruments.

Among submarine tunnels the Severn holds first place on the score of difficulty in construction. Mr. Walker himself confesses in his book that one such tunnel was sufficient for a single lifetime.

CHAPTER XII

THE SIMPLON TUNNEL

An entertaining volume might be written on the conflicts between the snow-clad, storm-swept Alps, and man, the soldier and engineer. How stirring is the story of Hannibal and his Carthaginians, fresh from the burning sands of Africa, pushing through the icy horrors of the Little St. Bernard! And of Napoleon, snatching a shovel from the numbed grasp of a pioneer to lead the attack on the drifts of the pass that lay between him and the famous field of Marengo!

Admirable as was the courage that enabled Carthaginian, Gaul, Goth, Hun, and Frenchman to triumph over the resistance of nature, we must not let the fascination which attends the clash of arms blind us to the romance of the later phases of the struggle, still being waged, though time has changed the fashion.

Now no longer is seen the train of elephants or baggage mules, and the glitter of spear and sword and bayonet. In their place we have the iron steed climbing steadily through the rocky fastnesses, and those wonderful weapons of the engineer, the theodolite and persistent mechanical drill. Armies occupy

the glens, but they are armies of workmen. Generals issue orders and direct the march; but the march is one of peace, more fraught with the good of mankind than was the passage of invading hordes.

What patience and skill is represented by the great tubes that pierce Mont Cenis, Mount St. Gothard, the Arlberg, and the Simplon! Yet the names of the men who planned and executed such deeds are unknown to the world at large, though every schoolboy is familiar with Hannibal and Napoleon.

The dash into the darkness of a tunnel is so frequent an occurrence on a railway journey that we reck little of it. Perhaps sometimes, after losing sight of the sunshine for several minutes, we have a dim consciousness that there has been wonderful work done on that part of the line; and we return to the perusal of our books and papers while our train speeds on over or through other engineering triumphs. Having eyes, we see not.

Think of the task that an engineer sets himself when he undertakes to burrow through a mountain for several miles. To save time he must commence the work at both ends simultaneously. To make sure of the headings meeting he must not put tool to rock until all his calculations have been made most carefully by compass and theodolite, and verified time after time. To deal with the water springs possibly lurking in the mountain's heart, he must drive the tunnel on a rising gradient to the centre—a much more complicated feat than a perfectly rectilinear

course. To give his men an atmosphere fit to breathe, special apparatus for ventilation must be installed that will force the outer air deep into the very heart of the rocky mass.

All this entails years of anxious and unremitting toil. At any moment he may find himself face to face with an obstacle that threatens the ruin of his enterprise: the fall of a stratum, the inrush of a subterranean reservoir. There are many foes waiting for him.

In short, so great are the uncertainties and difficulties of tunnel-driving that the engineer, when confronted by a range or mountains of hills, decides in favour of burrowing only when calculation has shown that the longest way round is not the shortest way home. In adding up the total advantages of an open road in cutting, and of a tunnel, there are many things to be considered and weighed one against the other, economy controlling the balance. A détour costs less in construction, and is sooner open for traffic. A tunnel is shorter, less expensive to maintain, and avoids the heavy gradients of the open way. But its initial cost is enormous, both in time and money. Fortunately for international communication, the great advance in the art of tunnel-building has done much to remove the principal objections to tunnels, and when the choice lies between a tunnel and a long détour with stiff gradients, the former generally wins the day.

Hence some of the most remarkable engineering triumphs.

The story of Mont Cenis and St. Gothard tunnels has been told so often that it will be here but briefly recapitulated as preface to an account of an even greater undertaking still in progress beneath the Simplon.

Between Italy and France runs the range known in its different portions as the Graian and Cottian Alps. Prior to 1871 the Fell Railway, laid on the road built by the first Napoleon, transported travellers across the frontier. This track proving insufficient, Italian engineers began their surveys for a tunnel under the Grand Vallon, that should connect the Paris-Marseilles railway system, by means of a branch from Macon, with the Italian lines that converge on Turin. The work, commenced the same year, was, thanks to the aid of the newly invented air-drills of Sommeiller, completed in 1871 at a total expenditure of £3,000,000.

The following year witnessed the inauguration of a similar scheme for piercing the Mount St. Gothard, and linking up Belgium, Germany, and Switzerland with Italy, *viâ* Bâle and Lucerne. Nearly 300,000,000 francs were guaranteed by the countries most interested in the undertaking, and after the changes and chances of ten years, marked by labour and financial difficulties, the death of M. Favre, the contractor, and the Franco-German War, the tunnel was opened to traffic. In addition to the main tunnel, 9⅓ miles long, the engineers constructed several wonderful helicoidal (*i.e.* corkscrew-shaped) tunnels on the ap-

proaches, in which the track doubles back and over itself in a manner most bewildering to the traveller.

Length for length, the St. Gothard was driven almost twice as fast as the 8-mile Mont Cenis (or more properly, Grand Vallon) tunnel.

The cry was still for "more." A glance at the map of Switzerland reveals a railroad running from Lausanne along the north shore of Lake Geneva, and on through the Rhone Valley to a terminus at Brieg. On the Italian side of the neighbouring Lepontine Alps, the northern lines throw out a feeler to Arona, at the south end of Lake Maggiore. Between these termini the only present means of communication is a daily service of coaches, running over the fine mountain road. But this will soon be a thing of the past, as a tunnel is fast penetrating the Simplon in a straight line from Brieg to Iselle, a small town on the upper waters of the Diveria, a tributary of the river Toce. A new railway is being built from Arona up the Toce valley *viâ* Domo D'Ossola, to complete the connection and provide a new route from Paris to Genoa by way of Dijon, Portarlier, and Lausanne.

The Simplon tunnel will have an ultimate length of 12⅓ miles, of which 12 are on the straight, the line curving away at the ends to join the open tracks. At the centre there will be a level stretch of about 750 yards. From this the line falls gently on a gradient of 1 in 500 to Baffi, at the Swiss end; and by a more sudden descent of 1 in 143 to Iselle in Italy. The highest point being but 2314 feet above

sea level, or 1474 feet less than in the case of the St. Gothard, the cost and difficulty of haulage will not be nearly as great as that of the more easterly route, and only one helical tunnel—on the Italian side—is necessary for the approaches.

The Simplon differs from the Mont Cenis and St. Gothard undertakings in that the tracks will run in separate parallel tunnels, the axes of which are 56 feet apart. At present only one of these is being completed to full section (19 feet 6 inches by 19 feet 6 inches). The other will be enlarged from its temporary dimensions (10 feet by 8 feet) as soon as the need arises, at a much smaller cost than the first. Every 220 yards cross-passages are cut between the two tunnels, the most recent only remaining open to promote the proper ventilation of the workings. This subsidiary work, which for distinction's sake may be styled tunnel No. 2, has also proved most useful for drainage, the storage of material, and as a conduit for the compressed air and water pipes.

The determination of the centre line of so long a tunnel running under a series of lofty peaks is no easy matter. It being impossible to pick out a straight line immediately over the proposed path of the tunnel, mark it, and guide the operations by observations of these marks from time to time, the surveyors, after setting two fixed points, one at each end of tunnel No. 1, had to calculate the path of the excavations by means of triangulations struck from eleven peaks, of which Monte Leone holds the central position.

"On the top of each summit is placed a signal, consisting of a small pillar of masonry founded on rock, and capped with a sharp pointed cone of zinc, 1 foot 6 inches high. An observatory was built at each end of the tunnel in such a position that three of the summits could be seen, a condition very difficult to fulfil on the south side owing to the depth of the gorge, the mountains on either side being over 7000 feet high. Having taken the angles to and from each visible signal, and therefrom having calculated the direction of the tunnel, it was necessary to fix, with extreme accuracy, sighting points on the axis of the tunnel, in order to avoid sighting on to the surrounding peaks for each subsequent correction of the alignment of the galleries. To do this, a theodolite 24 inches long and 2⅜ inches in diameter, with a magnifying power of forty times, was set up in the observatory, and about 100 readings were taken of the angles between the surrounding signals and the required sighting points. Thus, at the north end two points were found about 550 yards before and behind the observatory, while on the south side, owing to the narrowness of the gorge, the points could only be placed 82 yards and 176 yards in front. One of these sighting points consists of a fine scratch ruled on a glass in an iron frame, behind which is placed an acetylene lamp — corrections of alignment are always done by night—the whole being rigidly fixed into a niche cut in the rock, and protected from climatic and other disturbing agencies by an iron plate.

"The direction of heading No. 1 is checked by experts from the Government Survey Department at Lausanne about three times a year, and for this purpose a transit instrument is set up in the observatory. A number of three-legged iron tables are placed at intervals of 1 mile or 2 miles along the axis of tunnel No. 1, and upon each of these is placed a horizontal plane, movable by means of an adjusting screw, in a direction at right angles to the axis along a graduated scale. On this plane are small sockets, into which the legs of an acetylene lamp and screen, or of the transit instrument, can be quickly and accurately placed. The screen has a vertical slit, 3 inches in height, and variable between $\frac{13}{16}$ inches and $\frac{3}{16}$ inches in breadth, according to the state of the atmosphere, and at a distance shows a fine thread of light. The instrument, having first been sighted on to the illuminated scratch of the sighting point, is directed up the tunnel, where a thread of light is shown from the first table. With the aid of a telephone, this light is adjusted so that its image is exactly coincident with the cross hairs, and the reading on the graduated scale is noted. This is done four or five times, the average of these readings being taken as correct, and the plane is clamped to that average. The instrument is then taken to the first table, and is placed quickly and accurately over the point just found (by means of the sockets), and the lamp is carried to the observatory. After first sighting back, a second point is given on the second table, and so on.

These points are marked either temporarily in the roof of the heading by a short piece of cord hanging down, or permanently by a brass point held by a small steel cylinder, 8 inches long and 3 inches in diameter, embedded in concrete in the rock floor, and protected by a circular casting, also sunk in cement concrete, holding an iron cover resembling that of a small manhole. From time to time the alignment is checked from these points by the engineers, and after each blast the general direction is given by the hand from the temporary points." [1]

The accuracy of the surveyor's calculations is one of the greatest marvels of modern engineering. In the Mont Cenis tunnel the error was but a matter of 1 inch in 8 miles; in the St. Gothard about a foot in 9 miles, quite negligible quantities.

The contractors, Messrs. Brandt, Brandau & Co., of Hamburg, signed in May 1898 the contract for the entire completion of the work by May 13, 1904, or within five and a half years of the commencement on November 21, 1898. For every day in excess of that period a fine of 5000 francs (£200) will be imposed, and for every day less the contractors earn a premium of equal amount. Epidemic, war, or mutual lassitude of Italy and Switzerland, are fixed as the only causes for the cessation of work. Should the operations continue for more than a year beyond the stipulated time, the contractors will hand over the execution to the Jura-Simplon Company.

[1] From "Tunnelling," by Charles Prelini and Charles S. Hill.

The contract price is 69,500,000 francs, or about £2,780,000.

The progress of the tunnel is shown in the following figures. In 1898, out of a total of 21,564 yards, 447 were completed:—

By the end of 1899 . .	4,227 yards
" 1900 . .	7,947 "
By August 1901 . . .	10,790 "
By June 1902 . . .	13,345 "

Since then the rate of advance has been steady, and we may expect that, unless some unforeseen obstacle of unusual proportions presents itself, the work will be successfully concluded in contract time.

A simple calculation shows that the average advance from November 1898 to June 1902 was 31 feet a day. During part of this period Sunday was considered a *dies non* by the workmen; and the yearly holidays being also subtracted the average then rose to 33 or 34 feet per diem. Compare this with the average 7¾ feet of the Mont Cenis, and the daily 13½ feet of the Mount St. Gothard, and the rapid development of the art of tunnelling is evident. In justice to M. Favre we must, however, admit that the total section of the two Simplon tunnels is not equal to that of the single St. Gothard; but even when due allowance has been made on this head, the contrast in speed is marked.

One of the greatest difficulties in tunnel-driving through mountains arises from the need of proper

ventilation at the working-face. The heat of a tunnel increases with the altitude of the superincumbent mass. At the centre of the Simplon, where 6000 feet of rock cover the workings, the heat would be unendurable but for artificial means of cooling, while the fumes from the explosives would render the air unfit for respiration, were it not constantly replaced by fresh supplies from outside the tunnel.

The plant for ventilation and transmission of power, shops, hospitals, laundries, and other establishments for the convenience of employés, are practically the same at Baffi and Iselle. It will therefore suffice to describe what is seen at the Italian end.

The first thing that attracts our attention is the power-house, containing three Escher-Wyss turbines, two of 250 horse-power, and one of 600 horse-power, running at 170 revolutions per minute. To these are attached ten pumps for supplying water to hydraulic accumulators at a pressure of 1764 lbs. to the square inch. From the accumulators the water passes through 4-inch pipes up the tunnel to the working-face, where it actuates six rock drills, to be described presently.

It is fortunate for the contractor that he can at a comparatively small cost harness the force of the Diveria to his drills. The river has been dammed about 2½ miles above the power-house, and turned into two reservoirs connected with the turbines by large pipes, cast-iron for the first 1440 yards, and then built up of steel plates ¼-inch thick. At the power-

house the pressure of the water is about 250 lbs. to the square inch.

A special pair of 200 horse-power turbines does all the ventilating of the Italian excavations. Each drives a fan 12¼ feet in diameter and 3 tons in weight, which forces air through a 14-inch pipe to the working-face. The pipe is carried along close to the roof of the tunnel, and is added to as the excavation proceeds.

We notice the two electric-light stations each supplying current for 32 arc lamps of 500 candle-power, and 100 16-candle-power bulbs. Passing the machine-tool shop, where are installed lathes, planing machines, saws, &c.—all worked by turbines—we come to the smithy and foundry, a most important part of the workshop. Their principal function is to make and repair cutters for the Brandt borer, invented by and named after the contractor.[1]

The welfare of the employés has been provided for in the bath-houses, where every miner can have a bath or douche when he leaves the tunnel at the end of his shift; and in the laundries and drying-rooms, where the dirt and moisture is removed from his clothes. Instead of a locker each man has a numbered cord supporting three hooks, and a soap dish, which, when loaded with their owner's belongings, are hauled up to the ceiling out of the way, and into the warm upper stratum of air. At the restaurants excellent food is provided for the very moderate sum of

[1] Sad to relate, the same fate overtook MM. Favre and Brandt—death from apoplexy before the completion of their great works.

11d. a day; 2d. more ensures the miner a comfortable bed in rooms lit by electric light. So that his bodily needs are well cared for.

Débris is removed from, and material carried into the tunnel by trucks and engines running on a line of 31½-inch gauge. The engines are of two types, steam and hot-air. The steamers have very large boilers, so that when steam is once up they may make the journey to and from the working face without any need for stoking, and the consequent fouling of the atmosphere. Their height to the top of the boiler is but 6 feet 6½ inches; and the short 14-inch funnel is provided with a hinge for lowering it in confined spaces.

The air locomotives are used chiefly in the headings. Their freedom from fire and steam fits them for haulage in the farthest interior, where coolness is of great importance. The compressed air, driving a single cylinder that actuates the 2-foot road wheels through intermediate gearing, is stored in 27 cylinders, at a pressure of 1030 lbs. to the square inch; the supply being renewed when necessary from an air-valve situated 1¾ miles from the entrance, and connected by piping with compressors at the power-station.

For the following description of the southern or Italian end of the excavation, the writer is largely indebted to an account that appeared in the columns of *The Engineer*.

The men work in three shifts of eight hours each.

Their day is reckoned, Jewish fashion, from 6 P.M. till 6 P.M. Seven days a week the operations go on, as soon as the boundary line between the two countries has been passed; for the Italian workmen, who obey their priests in the matter of Sabbath keeping while in Italy, declare that they "have no religion" when once they enter Switzerland. "This is the only blot on the undertaking, for, in the opinion of tunnel experts, no loss of time, but rather gain, is secured by allowing men, horses, and machinery to rest for the one day in seven. As it is, work goes on incessantly from one year's end to another, with the exception of four or five days which are particular feasts, or are days on which the special Government engineers appointed for verifying the axis of the tunnel require cessation of work for getting their lines into the tunnels from their telescopes and theodolites."[1]

The men are encouraged to exert themselves by a system of premiums. Each gang benefits by any daily advance over the average. The work is so unpleasant and exhausting, that but for some such arrangement there would be flagging, with loss to the contractors.

Trains, running to a regular time-table, convey men and materials in and out of the tunnel about 30 times a day; punctuality in starting and arrival being strictly observed.

The air at the entrance is described by a visitor as a

[1] *The Times*, August 29, 1901.

more sulphurous edition of that of the London Metropolitan Railway. As the "face" is approached the temperature falls, until we enter the comparative comfort of the fresh-air supply. The tunnel is well lined with Antigorio gneiss, the spoil of the excavations. Every 100 metres a "refuge" is let into the south-west wall, and at every 1000 metres small cellars have been constructed for the storage of supplies and signalling apparatus.

At the "tunnel station" passengers quit the train, and proceed on foot to the scene of excavation, where springs of water are unpleasantly in evidence. The temperature of these inflows shows that they are due to leakage from the surface, and not to the proximity of a subterranean reservoir. On the Italian side of the mountain the first 4350 metres pierced were through gneiss, hard but comparatively free from moisture. Then followed a short section—40 metres long—of micaceous schist, that has proved to the contractors much what the Great Spring was to Mr. Walker in the Severn Tunnel.

The schist, being softer than the rock, is squeezed into any excavation piercing it. So great was the pressure that timbers 16 inches square, packed closely together, broke up like matchwood, and blocked the boring. After six months of hard work the engineers succeeded in replacing the wooden with iron frames formed of girders 15¾ inches deep, 6½ inches wide across the flanges, and ⅝ inch thick in the plates. Stout timbers bolted to each side of the frames

greatly increased their strength. In the first portion of the "fault," 32 frames were placed contiguously; but in the farther part spaces of 16 to 48 inches, filled in with concrete, separated them according to the plasticity of the schist.

The difficulty of erecting these frames was, as may be imagined, very great, at one time apparently insurmountable, if the engineer's vocabulary admits such a word. The delay, in addition to the extra work, entailed a great increase of speed in the boring beyond, where the rock is more amenable, to make up for lost time.

The frames allow an internal passage, 8 feet 2 inches by 9 feet 2 inches. The material all round them had to be cleared away for a generous distance to admit an unusually thick lining of masonry. The removal of the schist has proved a very tedious business, since care must be taken not to leave the frames unsupported for more than a few feet at any one place.

Excavation commenced by cutting a hole through one of the side posts sufficiently large to pass workmen and materials. The men chiselled a short shaft downwards, and then drove a heading under the base of the frame to the centre line, and the half of the invert (or arch with the concave side upwards, of gentler curvature than the tunnel roof) was built in. Meanwhile other hands tunnelled below the farther side of the frame; and when they too reached the centre line, and put in their half of the masonry,

a section of the tunnel bottom was finished. The work proceeded after this manner in rings a few feet apart.

The sides and upper arch have next to be dealt with. It has been proposed to build these in when the interval between the outside of the frames and the inner side of the tunnel lining has been cleared and filled with temporary masonry, which will serve as a support for the timbering in the space actually occupied by the lining. The completion of this short length will probably require a total of nearly two years' work.

It was found impossible to drive the smaller tunnel forward through the fault, so the engineers abandoned No. 2 heading for a time, and when No. 1 heading was lined, cut a cross passage and burrowed backwards.

At the working face three Brandt hydraulic drills, mounted on a beam wedged across the heading, are eating holes into the rock for the reception of the blasting charges.

A short description of these drills is pertinent, as they have played so important a part in the excavation. On the Mont Cenis and St. Gothard tunnels the holes were bored by percussion air-drills, making 200 strokes a minute. During the driving of the Arlberg Tunnel (1880–1884) a trial was given to Brandt's invention, which revolves a hollow cutter, 2¾ to 3½ inches in diameter, held against the face of the rock by an hydraulic ram exerting a pressure of

about 10 tons. A couple of small cylinders drive the mandrel holding the cutter through worm gearing, and the exhaust water issuing from them is shot up the centre of the drill, serving the double purpose of cooling the metal and removing the detritus.

The severity of the work soon wears down the three fangs at the cutting-edge, which must be re-formed in the smithy, where 300 to 500 cutters are treated daily, according to the nature of the stratum encountered, and in addition 1000 to 3000 hand chisels.

The drills are tended by fourteen or fifteen of the smartest miners, capable of sustained work under most trying conditions, and supervised by a foreman and engineer. The slowly revolving cutters having made eleven holes 3 feet 3 inches to 4 feet 7 inches deep in the face, the drill beam is twisted round on its truck and run into a place of safety. Then the dynamite truck advances with its deadly load. Special workmen place 6 lbs. of explosive into each hole, fix the detonators and fuses, and ram in fine borings behind as "tamping." When all is ready the fuses are lit, and every one quickly withdraws into shelter. From their refuge the men count the reports, which are accompanied by a violent rush of air and dense fumes. The last are precipitated by jets of water from the high-pressure hydraulic main, let loose after each explosion.

Ten minutes having elapsed since the last discharge, the men return to the heading to pile the débris into trucks, which are hauled out by small ponies to the

air-locomotives, which pass them on to the steamers. Each "lift," or advance, of the drills removes 264 cubic feet of rock. In hard rock only three or four lifts are made a day, but in soft the number rises to eight or ten.

The general method of clearing out the workings to full section is similar to that already described in connection with the Severn Tunnel. The blasted passage serves as the lower heading, from which shafts are chiselled upwards to the elevation of the tunnel crown, to act as starting-points for the upper galleries. As soon as the arch has been quarried out, the floor separating the two headings is cut away, and the lower portion enlarged. Wherever necessary, an elaborate system of timbering insures the safety of the workmen, and prevents the caving-in of the sides. The masons follow hard behind the excavators, and put in the lining of stone.

When the tunnel is completed, special attention will be paid to its ventilation. At Brieg and Iselle the entrances are to be provided with stout curtains to turn the air from one tunnel to the other through a cross passage at the extremities. Air forced in from Brieg will travel to Iselle through one tunnel and return through the other. The same effects will result from suction. The curtains are of a material which will not offer sufficient resistance to damage a train, if by accident they are not removed in time for its transit.

Marseilles is a long way from the Simplon, yet the Marseillais will feel the effects of the tunnel. On the

opening of the Mont Cenis route, the eastern mail services were transferred from Marseilles to Brindisi, and passengers also largely used the same means of shortening the journey to India. Another serious blow at the prosperity of the great southern French port was struck by the St. Gothard tunnel, which places Bâle 135 miles nearer an important harbour (Genoa) than it is to Marseilles. Consequently, all the merchandise sent from England, Belgium, Holland, and German Switzerland now goes to Genoa by rail for shipment to the Mediterranean sea-board. The completion of the Simplon project will still further increase the commercial importance of Genoa at the expense of Marseilles; and the position has become so serious that plans have been proposed for connecting the latter town with the Rhone at Bras Mort by a canal 34 miles long, skirting the Gulf of Lyons for part of its course. The work is estimated to cost 8,000,000 francs.

A canal 20 feet deep would enable vessels of 1000-tons displacement to reach points 300 miles up the river; and if the cargoes were transhipped to 300-ton barges, they could pass over the existing system of internal waterways to Nancy, Paris, Havre, and Lille. The cost of water transport being but one-half of that by rail, especially in the case of heavy merchandise such as coal and other minerals, Marseilles may win back to herself much of the traffic that has been diverted by the far-away tunnels in the Alps.

CHAPTER XIII

THE MANCHESTER SHIP CANAL

A STRANGER dropped suddenly among the quays and wharves of Manchester, seeing around him great ships upwards of 9000-tons burden, great cranes unloading cargoes, and hundreds of waggons and railway trucks receiving the same from towering warehouses, would at once exclaim, "Surely this is not far from the salt sea waves!" and might imagine that the breezes rippling the broad expanse of water before him are blowing fresh from the open ocean. But let him board yonder vessel just casting off her moorings for an outward voyage, and follow her fortunes for a few hours, and he will understand that the road to the true home of all this shipping is a long one, and that Manchester has lured these shapely masts and smoking funnels far into the heart of Old England by a waterway that stands among the foremost of the world's engineering romances.

Let us accompany our passenger, and through paper and ink see what he sees.

As we pass by the long wharves lining the water, the channel gradually contracts to a width of some 250 feet, but widens to 400 as we approach the Mode Wheel Locks. These are two in number, the one 600

feet long by 65 broad, the other 350 feet by 45. Our vessel enters the smaller, and in five minutes has descended 13 feet towards sea level. We proceed for $2\frac{1}{4}$ miles, over what was once the bed of the Irwell, until our attention is arrested by a curious sight—a barge borne aloft in mid-air in a gigantic iron trough, known as the Barton Swing Aqueduct. How did the barge get there? Look to left and right and you behold, far above the canal level, two iron gates. Behind these the Bridgewater Canal is pent, while a section of it is calmly swung round — also enclosed by shutters at each end—with its floating freight, that we may pass. As we drop into Barton Lock, the hydraulic machinery on the mid-channel pier slowly brings the trough athwart our pathway, and in a few minutes the bargeman is urging on his horses *en route* to Worsley.

The country north and south of us is studded with the numerous towns that make this the most thickly-populated district of England. Had we but ears to hear, the whirr of innumerable spindles would speak to us of the great cotton industry of which Manchester is the heart; and into which the Canal is pouring the life-blood of commerce, to be distributed by the lesser arteries and veins of waterway and railroad.

A few miles, and we slow up once more for the passage of Irlam Lock, which lowers us another 16 feet; and when freed we pass under a great railway bridge, and note on our left the entrance of the Mersey into the Canal. Our voyage is unbroken for

7 miles. Inland-bound vessels pass us at a stately pace of 5 to 8 miles an hour. There is no need to make for a "siding" to give the other room, as the Canal has a generous width—120 feet at bottom, increasing to nearly double near the locks. At Rixton Junction the Canal leaves the river-bed, and becomes purely artificial for the remaining 24 miles of its length. At Latchford, 14½ miles from Manchester, we again enter a lock, and drop from (comparatively) fresh into salt water, for at certain states of the tide no barrier is interposed between Latchford and the sea. We are now 60 feet lower than our starting-point, having descended in four bold steps.

Sailing with a straight course, we come to Runcorn, an important town on the now broadening Mersey. The river is within a stone's-throw of our boat, but it will be a long time yet before we enter its waters. The canal now makes two sweeps, the first southwards from Runcorn, the second gradually northwards along the southern bank, behind great embankments dividing the Canal from the river. Eastham reached, we pass the open lock—for the tide is up—and pass out into the Mersey at a point 35½ miles from the great cotton town.

We may now glance at the history of this undertaking.

As early as 1721, the necessity for efficient water communication between Manchester and Liverpool—then a rising port—caused Mr. Thomas Steers, an engineer of repute, to issue plans for canalising the

Mersey and Irwell from Warrington—to which small vessels ascended on the tideway—to Manchester. His scheme was carried out and subsequently extended, to compete with the Bridgewater Canal, which united Manchester with the Mersey at Runcorn. The canal then absorbed the "Mersey and Irwell Navigation" in 1844, and the two became formidable rivals to the railways; and finally, in 1886, both were transferred to the Manchester Ship Canal Company for the sum of £1,712,000—a sufficient proof of their importance.

The first scheme for constructing a ship canal was mooted in 1825, when a Company was formed to unite Manchester with the Dee by a canal 51 miles long, containing fourteen locks. It came to nothing, however, sharing the fate of two later proposals, the second of which deserves short notice. In 1840 Mr. Henry Palmer drew up a plan for the Mersey and Irwell Navigation Company for deepening the existing waterway sufficiently to pass vessels of 400-tons burthen to Manchester. By means of training-walls built in the river above Runcorn he thought the concentrated scour of the tides might be compelled to keep open a channel with a minimum depth of 10 feet. Locks and weirs would be established in the upper river; so that ships of the size mentioned could all reach Manchester except those with fixed masts, which would be compelled to discharge cargo at Barton, where the Bridgewater Aqueduct crossed the course.

From a photo lent by] [*Manchester Ship Canal Co.*

A View on the Manchester Ship Canal.

[*To face p.* 248.

In 1882 the question was again taken up, this time with great energy. Seventy leading Manchester merchants and manufacturers instituted surveys and reports on the "feasibility of constructing a navigation to Manchester available for ocean-going vessels." Mr. H. H. Fulton and Sir E. Leader Williams undertook the surveys. The former was in favour of a tidal canal all the way to Manchester, where the rise of the country would necessitate a basin 90 feet below the level of the town. His colleague, however, spoke for a locked canal above Runcorn, on the grounds that the cost of excavation would be far less, and that the presence of locks would convert the river into a series of practically still-water pounds.

The latter plan was accepted by the Company, which in 1883 introduced a Bill into Parliament for constructive powers, but the application was thrown out by the House of Lords after passing the Committee of the House of Commons. When introduced again the following year, the Lower House in turn rejected it; but on a third attempt in 1885 the Company gained its end after the costs of introduction and opposition had amounted to £250,000.

The Committees left their mark on the Bill, however, for the Act demanded that for the training-walls in the Mersey should be substituted a semi-tidal canal along the Cheshire side of the estuary, entering the Mersey at Eastham, 6 miles above Liverpool, whence a good low-water channel led to the deep waters.

After some hesitation on the part of Lancashire

financiers, the necessary capital was subscribed, and the late Mr. T. A. Walker, of Severn Tunnel fame, obtained the contract for £5,750,000. On November 11, 1887, the first sod was cut at Eastham. On May 21, 1894, the late Queen Victoria formally declared the whole Canal open to traffic.

This titanic work necessitated the excavation of 54 million cubic yards, nearly a quarter of which was sandstone rock. At the busiest period 17,000 men were engaged, aided by 80 steam navvies and dredgers, 316 steam engines and cranes, 173 locomotives, and 6300 waggons and trucks running on 228 miles of temporary railway, the value of which plant approached a million sterling. The cost of the canal, including construction of works, the purchase of lands (£1,289,000), purchase of canals (£1,786,773), parliamentary expenses, general expenses, surveying, &c., amounted on January 1, 1897, to the huge total of £15,168,795, 15s. 11d., a sum greatly in excess of what the promoters had originally contemplated. It must be mentioned, however, that as the work progressed, the scheme enlarged itself in the direction of greater dock and warehouse accommodation, &c. The untimely death of Mr. Walker in 1889, by throwing the contract on to the Company, involved it in considerable loss.

As often happens in great engineering feats, the "unknown quantity" of unforeseen natural obstacles, such as faults in the strata excavated, and heavy floods, pressed hard upon the contractors and pro-

moters. In 1890 and 1891 winter floods worked great havoc with the cuttings. One cutting, in the Irlam division, was almost completed when the natural dam at the Manchester end, shutting it off from the river, suddenly gave way under the pressure of the spate, and in ten minutes over 250 million gallons of water had rushed into the cavity, bearing with it more than 100,000 cubic yards of material. When the water had been pumped out, under cover of a new dam, trains of waggons were found tied up in knots, and heavy machinery scattered far and wide. During the two years mentioned, no less than *twenty-three miles* of cuttings were filled prematurely by water, which had, of course, to be pumped out before work could proceed.

Retracing the course of the canal, we will remark upon its most noticeable engineering features.

Throughout its length excavation was needed, but in varying degrees. From Eastham to Runcorn, the level of the estuary at high tide being equal to, or greater than, that of the mean level of the Canal, embankments were necessary for long stretches. Between Runcorn and Latchford, where tidal action ends, the Canal leaves the river and enters higher ground, necessitating cuttings from 70 to 40 feet deep. From Latchford to the junction with the Mersey again the cutting is continued, but from the latter point to the confluence with the Irwell embankments once more are employed to keep in the water. The upper reaches of the Irwell required further

cuttings 30 to 40 feet deep. The depth of water is kept by the locks at 26 feet throughout, the gates at Eastham being closed as soon as the tide level of the estuary has fallen to that height above the bottom of the Canal. During the flow of the spring tides, the opened gates permit a greater depth up to Latchford. A peculiar feature of the Canal is the rapidity with which the tides work up to Latchford, where, at high spring tides, the level is raised to 9½ feet above normal about half-an-hour after high tide at Eastham, 21 miles farther down. Within 2½ hours of high water at Latchford all this extra volume has again left the Canal. The result is a strong current, which in turn entails the lining of the Canal side with stone facings, which have also to withstand the scouring action of a ship's wash. The latter consideration has indeed made such a protection necessary throughout the Canal, except in a few places where natural rock is met with of a sufficient height.

In the Eastham division of the Canal three large embankments were made, known as the Pool Hall, Ellesmere Port, and Ince Bay embankments. The method generally employed was to tip two parallel mounds of rubble on the foreshore to act as toes, or supports, for the lower edges of the embankment slopes, and then pile between them mounds of stiff clay.

At some points the engineers encountered great difficulties, owing to the pressure of a substratum of mud or sand through which the estuary water forced its way to the workings. In Ellesmere Bay especially,

for a distance of $1\frac{1}{5}$ miles, a particularly staunch protection was needed, for although at that time the deep channel of the Mersey lay on the north side of the river estuary, it had formerly passed close to the southern bank, and might return thither again. Accordingly for 5400 feet, two parallel rows of piles, 1 foot square and 35 feet long, were driven down contiguously into the sand so as to form two wooden walls 78 feet apart, the summits of which were at the bottom of the embankment. To make these subterranean walls the more secure, two additional rows of piles—shorter, and 6 feet apart—were sunk to the same level at distances of 20 feet from the inner row, and 25 feet from the outer row, and anchored to the sheet piling by stout cross timbers.

The driving of these piles, which represent a total length of 100 miles of foot-square balks, would have been practically impossible, not to say ruinously expensive, had force only been used. Recourse was therefore had to the erosive action of the water-jet, a device that has proved of immense use in many undertakings. A jet of high-pressure water was pumped by steam-engines through a pipe of $1\frac{1}{2}$ inch bore and 40 feet long, which preceded the pile in its downward course, softening and loosening the sand to such a degree that the pile easily pierced the stratum. Twenty-one pile-drivers were kept at work, the best week's record being 554 piles sunk into place.

As the rows lengthened a trench 15 feet deep was

excavated behind the piles for an average width of 12 feet, and immediately filled in with rubble and clay in equal amounts. This gave a firm and water-tight foundation for the superimposed embankment. At intervals cross dams were built from side to side of the Canal, so that the failure of one part of the embankment should not flood the whole of the works.

Just below Runcorn lock a concrete wall, 4300 feet long, is substituted for earthwork. The wall is founded upon sandstone rock at its extremities, its central portion resting on gravel. It has a bottom breadth of 22 feet, tapering to 16 feet at the summit, which is about 40 feet above the foundation. The vertical side facing the Canal is protected from damage by timber fenders. This wall is in itself a large and costly piece of construction.

So well have the engineers done their work, that after several years the walls remain staunch and sound, in spite of severe storms.

Some of the most difficult portions of the Canal are included in the Irlam division, which extends from the twenty-sixth to the thirtieth milestone above Eastham. The cutting here is deep, and, as the line of the Canal crosses the beds of the Mersey and Irwell many times, construction proceeded in short lengths across the bends, the river being allowed to pursue its natural course until each chord was completed. The dams at either side were then cut and the arc of river turned into the artificial channel, the dried bed being filled in with the spoil of the excavations.

The strata of blue clay, gravel, and alluvial deposit were of such a nature as to cause the sides of the cuttings to fall in and sometimes entirely bury the steam-navvies and other plant employed in excavation. At one place a "slip" was burnt and replaced in the hole made by its subsidence, but, as a rule, the slipped material was cleared away and lumps of rock and quarry rubbish substituted.

Most of the excavating was done by steam-navvies of English, French, and German design. The English machine is stationed in the bottom of a cutting, and works a great ladle attached to the end of a beam, scraping up the side of the cutting until the ladle is filled with its load of 1 to 2 tons of material. The arm then swings round and deposits the spoil into a truck. The foreign patterns resemble ordinary marine or river dredges, the earth, &c., being collected by an endless chain of small buckets working round a boom which is gradually lowered into the hollow eaten out by the buckets. The French navvies proved particularly useful in light soil or soft clay. The English make would deal with all sorts of material, including blasted rock, which defied the other types. Apart from the dry excavating these machines were serviceable, as the English navvy could be easily converted into a 10-ton crane by the removal of the ladle, while a slight alteration of the French excavator fitted it for work under water.

Thanks to these powerful allies the rate of excavation attained 250,000 cubic yards a month in the

Irlam division alone. Even when rock was handled the total for the same period reached 100,000 cubic yards.

In several places the excavated material was used in the deviations constructed to carry the railroads that cross the Canal at various points. The interruption to passenger traffic would have been so great had opening bridges been employed that the Canal Company adopted high-level viaducts, the under side of which was 75 feet above the level of the canal. In order to preserve a gradient not exceeding 1 in 135, embankments of great length were unavoidable, and their construction cost the Company no less than £875,000. There are four railroad deviations; one at Warrington to carry the London and North Western, and Grand Junction lines; another at Latchford for the Warrington and Stockport Railway; a third at Irlam; and a fourth at Cadishead; the two last for the Cheshire lines. The girders spanning the Canal vary in length from 150 to 300 feet according to the angle of their crossing.

Nine important high-roads had also to be given a passage. At Warburton and Latchford small editions of the Forth Bridge afford a permanent means of communication at the same height as the railway viaducts. The remaining seven are swing bridges, revolving on masonry pillars, with spans ranging from 75 to 140 feet. The Moore Lane Bridge may be taken as typical. It is 238 feet from end to end of the span, the longer arm 240, the shorter 98 in

length. The main girders are 27 feet 8 inches deep at the centre, diminishing to 6 feet and 8 feet 9½ inches at the extremities of the arms. These girders rest on a square of cross girders, attached to the upper roller-path. A live ring carrying 64 conical rollers separates this from the lower roller-path on the top of the masonry pier. The whole is swung round by hydraulic machinery.

The most interesting feature of the Canal is undoubtedly the Barton Swing Aqueduct, to which allusion has already been made. The Bridgewater Canal, built in the eighteenth century for the Duke of that name by the famous Brindley, connected the Worsley coalfields with Manchester, and subsequently Manchester with Liverpool. The Canal was, and is, considered a wonderful feat on account of the bold project, successfully carried out, of its engineer to keep it absolutely free of locks into Manchester by raising embankments and viaducts, and cutting tunnels wherever the ground level fell away or natural obstacles intervened. To cross the Irwell he built a stone and brick aqueduct, which was the first of its kind, and one of the Seven Wonders of its time. When the Irwell became in turn a canal, the question arose how one waterway should cut the other. The smaller must, of course, give way to the more important, but the construction of locks from the higher to the lower level would entail a waste of water which the Bridgewater supply could not make good. Sir E. Leader Williams met the difficulty by a conception

as unique as that of Brindley. The Canal should not have its level interfered with, but a section of it should be bodily moved out of the way of passing steamers. The masonry was pulled down and replaced by an iron trough resting at its centre on a pier rising in mid-channel. The following is a description given by its designer[1] :—

"The pier is mainly built of concrete, with brickwork and granite in the part that takes the weight of the aqueduct, 1400 tons, including the water which is always in the iron trough through which the barges pass. The sides of the trough are 1 foot above the water level ; it is carried by side girders 234 feet long, 22 feet 3 inches apart from the centres of the girders, which are 33 feet deep, tapering off to 28 feet 9 inches at the ends, with a side tow-path carried on a gallery 9 feet above the water level. Water-tight iron swing-gates are provided at each fixed shore end, and also at each end of the trough ; when all four gates are open, barges pass along the Canal as usual. If a ship is to pass through the aqueduct all the gates are closed, the shore gates keeping back the water in the Canal, and the other gates confining the water in the trough when it is swung open for the passage of the ship. The gates are worked by hydraulic power, as is also the trough, which can be swung with barges in it, the gross weight to be moved remaining the same. At each end of the trough a water-tight joint is made by an iron wedge-piece of the shape of the cross section

[1] *Proceedings of the Institution of Civil Engineers*, 1897–98.

of the end of the trough, both ends and bottom being faced with india-rubber. The fixed and movable ends of the aqueduct are slightly tapered, and about 1 foot apart; this vacancy is filled by the wedge-piece, which weighs about 12 tons, and is lifted by four hydraulic rams sufficiently to allow the trough to be moved, the water between the gates being passed off into the Ship Canal. The junctions just described are not at right angles to the trough, but are slightly diagonal, so as to allow sufficient clearance for moving the trough. After it has been again closed, the wedge-piece is dropped on to its seating, being of the same taper as the ends of the trough and aqueduct.

"The arrangement of the annular girders, rollers, &c., are the same as those for the heaviest swing-bridges already described, but half the weight of the movable portion of the aqueduct is taken by a central hydraulic press, 4 feet 9½ inches in diameter and 2 feet 3 inches deep, which acts as a pivot and is free to turn; a hydraulic buffer and locking bolts are also provided. The power is obtained from the adjacent hydraulic station, which is also used for the road swing-bridge. The aqueduct has never given any trouble, working quickly and with smoothness, a result for which much credit is due to the constructors, Messrs. Handyside & Co."

Not many miles from Barton may be seen another remarkable instance of barges moved in closed troughs with the same object of avoiding lock wastage. At Anderton, some little distance south of Runcorn,

the Trent and Mersey Canal meets the Weaver Navigation at a point where there is a difference of 50 feet in their levels. Barges up to 100 tons displacement are transported from the one to the other by means of a double hydraulic lift, working vertically. Two troughs, each weighing with contents 240 tons, are supported on two cast-iron rams placed under their centres, the cylinders of which are connected by piping. When both troughs are full the pressure on the rams is equal, and no movement takes place. But on 6 inches of water being transferred by syphons from the one trough to the other the heavier forces up the ram of the lighter. Similar lifts have been since constructed at Fontinelles, on the Neufosse Canal in France, at La Louvière, on the Central Belgium Canal, and at Peterborough, on the Canadian Trent Canal. This last has a rise of 65 feet. The second transports vessels of 400-tons burden.

Among the other chief features of the Ship Canal we must include the Weaver sluices, the locks, and the Manchester Docks.

The River Weaver entered the Mersey about 2½ miles below Runcorn. When the embankment was built between the canal and the estuary the natural passage of the river was cut off, and it became necessary to provide means for letting the waters of the Weaver into the estuary in the same period of each tide as they would have passed into the estuary if the Ship Canal had not been made. Great sluices were therefore erected on the embankment on a platform of

masonry 470 feet long and 3 to 4 feet thick, protected on both faces by sheet piles and stones against the undermining action of the water passing over.

Steel caissons 36 feet long and 9 feet wide were built into the platform to contain the lower part of the piers between the sluice gates, which are ten in number, each 30 feet wide, with a lift of 13 feet. A bridge passing over the tops of the piers carries the winding-gear, by means of which two men can easily raise the ponderous gates.

Since the Weaver is practically the only route by which Cheshire salt can reach Liverpool for export, any derangement of traffic over the Navigation would have spelt heavy loss to the salt mines and the British salt trade. Under the Ship Canal Acts the Company had to permit Weaver salt barges a free use of the Ship Canal to Eastham, unless their tonnage exceeded that of those previously used. Chemical and other traffic had to pay the usual tolls to the Company. If the owners preferred it, however, the barges could drop into the Mersey at Runcorn, or Weston Mersey locks.

The locks on the direct course of the Canal at Latchford, Irlam, Barton, and Mode Wheel, are duplicated; a 600 by 65 lock lying parallel to one 350 by 45 feet. By means of intermediate gates these can be subdivided into smaller lengths of 150 and 450 feet, and 120 and 230 feet respectively, so as to pass craft of all sizes with the greatest possible economy of

time. Large culverts running along the lock walls fill the 350-foot lock in 4½ minutes, and the other in proportionate time. Between the smaller lock and the southern bank of the Canal—which doubles its breadth at the locks—is a weir pierced by 30-foot sluices to pass all surplus water. In flood time these are especially useful; on such occasions some of the spate is discharged through the embankments into the upper reaches of the Mersey estuary.

At Eastham, a third lock, 150 feet long, is added the 600 and 350-foot locks having their width increased to 80 and 50 feet. The cement used in the construction of the locks was subjected to severe tests; a notice of which may be interesting to those readers who are unacquainted with the properties of this material.

The cement was tested fourteen days after delivery. Samples taken from every 30 tons were first passed through sieves of 2000 meshes to the square inch, and all cement rejected which left a residue of more than 10 per cent. in the sieve.

Briquettes having a sectional area of 2¼ square inches were then made and submerged in water for eight days, at the end of which time their power to resist tensile stress was proved. The minimum permitted was a pull of 700 lbs.; some stood a stress of 3000 lbs., or about 1¼ tons, without breaking; but the average resistance was about 1000 lbs.

All cement used in the Forth Bridge foundation had to undergo equally severe tests; for we read that

the contractors required a briquette of 1 square inch section to resist a pull of 400 lbs. at the end of seven days. In fact, owing to the large amounts now used, cement for all important works is submitted to a rigorous system of testing and analysis before being accepted from the manufacturers.

The Manchester and Salford Docks, which commence at Mode Wheel Locks, have an area of 104 acres, 152 acres of quay space, and a frontage of 5 miles. These figures are, however, only temporary, since new docks are in course of construction. Dock No. 9, will alone have a frontage of over a mile, and Dock No. 10 will be of almost equal dimensions. The quays carry sheds and warehouses, rising to seven storeys, and over 30 miles of railway sidings. They are equipped with steam, hydraulic, and electric cranes and other appliances for quick dispatch. There is also a grain elevator of 40,000 tons capacity.

That, owing to the huge expenditure incurred by the Company, the shareholders of ordinary stock do not find their investments profitable, will be evident enough on reference to the quotations of the money market. At the same time, it would be a great mistake to condemn this magnificent engineering achievement as a commercial white elephant.

We must remember that the Ship Canal is in direct communication with the whole of the inland navigations of the country; that the area to and from which the canal traffic is carted contains 2½ million people,

and that in the districts nearer to the Canal than to any other ocean steamship port is found a fifth of the population of the British Isles.

A city far inland has become a seaport, with facilities equal to any on the coast, and this in spite of great opposition from rival interests and almost insuperable physical obstacles. Why? Because Manchester is the centre of one of England's greatest industries, which, owing to its natural position, was severely handicapped in competition with other progressive countries by the cost of transport to and from the ocean ports. If Manchester meant to hold her own, freights must be delivered at her very doors, unbroken, since "breaking bulk" often ate up the manufacturer's profits. The reduction in cost of transport and handling the 6,000,000 tons of cotton imported annually into the Manchester district has amounted to £500,000 sterling; and the total benefit, under this heading, to the community may be reckoned at more than double that sum.

A most eloquent testimony to the usefulness of the Canal is the external change that has come over the face of Manchester. Previously to 1880 the city showed decided traces of incipient decay. Many large works were moving to Glasgow and other ports, where they could save the excessive costs of carriage; empty warehouses boded the migration of trade. Since the opening of the Canal, new industries have started at the terminus and along the banks, the de-

serted mills and warehouses again teem with life, miles of new streets have been laid out, and renewed activity is seen on all sides.

The traffic returns increase steadily from year to year. In 1896 the whole receipts from the Ship Canal Department were £182,000, in 1902 they had risen to £358,491, or nearly double. In 1896 the profits were £65, in 1902 £140,955. These figures show that, though large accessions of traffic bring an increase in expenditure, that increase is not in proportion to the tonnage.

The Directors of the Company do their utmost to encourage merchants to use their Canal. Already suggestions have been made for deepening the Canal a couple of feet to accommodate vessels of 11,000 tons capacity—double the size of the largest cargo steamer afloat when the Act was obtained in 1885 for the construction of the Canal. Established lines of steamers ply between Manchester, America, the Mediterranean, and other parts of the world. As recently as January 1903 a regular fortnightly service was inaugurated with Boston; and the number of monthly sailings steadily augments.

Whatever may be the future fortunes of the Canal, nothing can detract from the public-spirited policy that brought it to completion, or from the skill and perseverance of its engineers. When Macaulay's New Zealander of the future has wearied of gazing upon the ruins of St. Paul's from the broken arches of London Bridge, he might with profit turn his steps

to the north. We feel confident that after a journey from end to end of the Canal, even if its channel has silted in, and its locks and wharves have fallen into decay, his verdict will be, "the people that did this work must have been a mighty race."

CHAPTER XIV

THE PANAMA CANAL

It is interesting to observe how considerate and at the same time unkind Nature has been to man, in her mode of moulding the earth's surface and in the distribution of sea and land.

She appears to have been undecided as to the relative advantages of an isthmus and a strait. At Suez she almost severed Asia from Africa, and then at the very last moment left a narrow neck of sandy desert. In Greece she ordained that the two portions should be connected so that men might pass from the one to the other dry-shod. Then with sudden whim she separated Africa from Europe at Gibraltar, cut Great Britain off from the Continent, while, on the farther side of the Atlantic, the two Americas were permitted to keep a gentle grip on one another at Panama.

It would, perhaps, be difficult to decide whether, taking human history as a whole, the junction of land with land has proved more useful than the union of sea with sea; whether the Gibraltar gap has benefited the Mediterranean countries more than it has hampered Spain and North-West Africa; whether the Bosphorus and Dardanelles have advanced Russia more than they have retarded Turkey and Asia Minor; whether

Egyptian civilisation gained or lost by the sandy strip at Suez; whether the Central American neck was or was not a boon to the continents it connects.

One thing is certain, that, as soon as a nation takes to the sea, it feels the shackles of a neighbouring isthmus. The Pharaohs endeavoured to join the Nile to the Red Sea. Xerxes and Nero in turn tried to breach the Isthmus of Corinth.

During the last fifty years uninterrupted land communication has been repeatedly sacrificed to the waterway, at Suez, at Corinth, in the Danish Peninsula, in Holland, since the shortening of a voyage by hundreds, or maybe thousands, of miles, far more than counterbalances the inconvenience of confining road and rail traffic to a few bridges.

The opening of the Suez Canal in 1869 marks an important epoch in the world's commercial history, one fraught, too, with great political importance. East and West could now join hands by sea without having to embrace the Cape of Good Hope. England and India are now but weeks instead of months apart.

The story of the Suez Canal has been told so often that a brief recapitulation will here suffice. Its central figure is M. Ferdinand de Lesseps, who resembled the great Brunel in the magnitude of his schemes, and like him was led by the energy of his genius into miscalculations of the cost of his projects. In spite of discouragement, technical, political, and financial, M. Lesseps insisted that his plan was practical, and that the desert sand could be kept at bay by dredgers when

once the channel had been completed and filled with water. By employing the latest mechanical contrivances he pushed forward a cutting, 75 feet wide at bottom, from the fine harbour specially built at Port Said, through the shallows of Lake Menzaleh, across 15 miles of desert, through Lake Balah, and more desert, to the long Bitter Lakes, whence a third stretch penetrated sandy waste to Suez.

During the six months that intervened between the opening of the Canal and the outbreak of the Franco-Prussian War of 1870, M. de Lesseps was the hero of Europe. The newspapers with one consent sang his praises. Crowned heads smiled upon him. Honours fell fast and thick. Wherever he went banquets and entertainments were his portion, especially in England, the country that benefited most by the successful conclusion of his enterprise.

But Nemesis was pursuing the over-fortunate engineer. Like Marius, the saviour of Rome, he was destined to outlive his reputation, and feel the bitterness of a fall from hero-worship to degradation in the eyes of his countrymen.

His star had, unknown to him, begun to set when he first cast eyes on the narrow Isthmus of Panama. Since Nunez de Balboa discovered the Pacific in 1513, that barrier between the oceans had already been the subject of many plans for connecting the Atlantic and the Pacific. In the sixteenth century Gomera the historian suggested a canal, which was also part of the projects of William Paterson, the founder of the ill-

starred Darien scheme of 1695. During the eighteenth century the piercing of the isthmus was discussed in Spain and elsewhere by men too numerous to mention. But only after the revolution in commercial relations throughout the world, produced by the opening of the Suez Canal, did there appear any chance of transforming design into fact.

In 1850–1855 an American company constructed a railway from Colon — formerly Aspinwall — on the Atlantic to Panama on the Pacific coast, at a cost of £2,500,000. Mr. A. Gallenga, writing in 1880, thus describes the country through which it passes: "The traveller has hardly left Colon five minutes before he finds himself wafted through the tangle of a primeval forest, by turns a swamp, a jungle, a savannah, yet a garden and a paradise; a strange jumble of whatever Nature can muster most varied, most gorgeous in colours, and sweetest in odours to delight a man's senses. Colon is built on a marshy island, separated from the mainland by a creek, which the train crosses soon after quitting the station. For a little while the land lies low, soaked at this season with green or yellow fever-breeding stagnant water, the surface of which is carpeted all over with those floating plants which the gardener's skill rears with infinite pains in English hothouses. But soon the ground rises and breaks up into gentle knolls, so densely wooded as to make the country round one impervious mass of green. The rank, hopelessly intricate vegetation invades every inch of space, pressing close to the very

rails of the line, and in deep cuttings, or in the hollows of the valleys, hanging so intrusively over it that in some places the company must be at no little trouble to make good its right of way, well aware that were it to slacken its exertions the whole track would be speedily obliterated. There is nothing imagination can conjure up to match the variety of the green hues, the vividness of the wild flowers of that virgin forest; nothing to equal the chaos of that foliage, as roots, stems, and branches crowd upon and struggle with one another, the canopy overhead being further tangled by hosts of lianes and other trailing parasites, blending leaf with leaf and thread with thread, like the warp and woof of a carpet."[1]

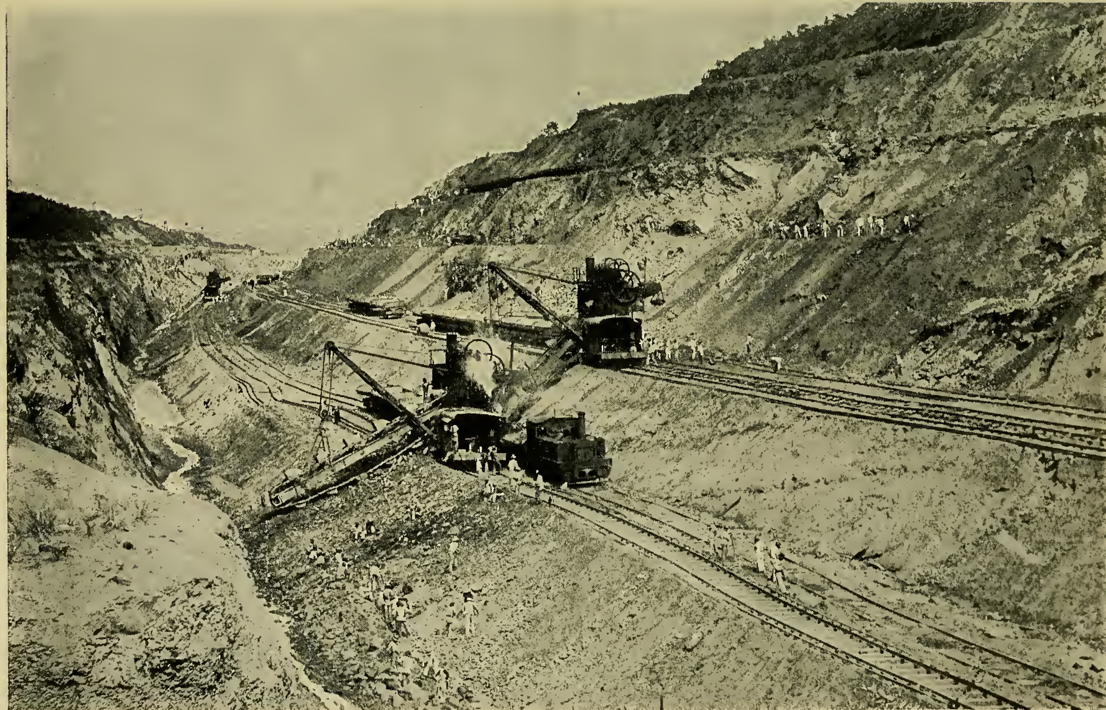
Since the railway route will be the subject of the following pages — as materially the same as that selected for the Panama Canal—its physiographic features may be also briefly noted. The isthmus between Colon and Panama witnesses a diminution of the "backbone of the Americas"—the Rockies and Andes—to an elevation scarcely worthy the name of a hill. On the Colon side the country for 20 miles rises very gradually; on the Pacific slope the ascent is more abrupt, reaching its highest point of 333 feet above sea-level in the now notorious Cerro de Culebra, and then sinking, with occasional upward gradients, to San Pablo. At Obispo the rail encounters the river Chagres, the course of which it follows at intervals northwards to Gatun, where the two separate

[1] "South America," by A. Gallenga.

at right angles. The influence of the river and Culebra Hill on the construction of the canal will presently be noticed.

In 1850 a treaty known as the Clayton-Bulwer was signed between the United States and Great Britain guaranteeing the neutrality of any canal cut across the isthmus. Twenty-six years later the French, elated by the success of the Suez Canal, organised in Paris an association to survey the isthmus with regard to the feasibility of a ship canal. A lieutenant in the French Army, M. Lucien N. Bonaparte-Wyse, was despatched to Central America to make the necessary investigations, and approach the Colombian Government on the subject of a concession to the association of rights to carry out his recommendations. The Government granted a charter whereby the grantees obtained "the free cession of all public lands required for the construction and service of the canal, of a belt of land 219 yards wide on each side of its banks throughout the entire length, and 1¼ million acres in localities to be chosen by the company." The concession was to endure for 99 years from the opening of the canal, after which period the canal would become the absolute property of the Government. The following conditions were, however, imposed: (*a*) That the rights could not be transferred to any nation or foreign government; (*b*) that the canal should be finished within twelve years of the formation of a constructive company.

When M. Wyse returned to Europe with his plans



By permission of] [*"Traction and Transmission."*

View of a Cutting on the Panama Canal.

[*To face p.* 272.

and treaty, M. Ferdinand de Lesseps, now seventy-five years of age, was chosen chairman of a Committee, and at once organised an International Congress to discuss the several schemes for constructing a ship canal. The chairman urged the adoption of a canal at sea level, which would resemble the Suez in its ease of navigation. It may be observed that several of the delegates strongly recommended a canal with locks.

The authority and enthusiasm of Lesseps, however, carried the day, and the public was invited to subscribe 400,000,000 francs. But investors hung back until after the chairman had personally visited the isthmus and decided the route of the Canal, when 600,000 shares of 500 francs each were quickly taken up. "Thus was born an Association destined to impoverish thousands of thrifty families, to besmirch the fair name of a great nation, to lead it to the verge of revolution, and rob it of any pride and glory in the completion of a work of world-wide utility and importance."[1] To those who review the situation, how pathetic it appears—upwards of 200,000 people investing, many their little all, in an undertaking foredoomed by peculation and corruption to failure; the famous engineer leading this great band of investors to a common ruin, as in 1870 Napoleon had drawn out his troops to meet disaster at the hands of the Prussians; the struggle against misfortune after misfortune; the final financial Sedan, that left behind it

[1] Mr. J. G. Leigh in "Traction and Transmission," February 1903.

"memories scarcely less bitter than those of the *année terrible*, 1870–71."

The period 1881–88 makes sad reading in the history of the Canal. In 1880 M. de Lesseps estimated the total cost at 843 million francs (£34,000,000). The following year he placed the figures at £20,500,000, in 1885 at £28,000,00. By 1886 £31,000,000 had been spent, by 1887 £40,000,000. When the crash came the total share and loan capital actually raised had reached the enormous total of 2,000,000,000 francs, and the work was not a quarter done!

The causes of this gigantic disaster, that desolated thousands of humble French homes, are manifold. First, the deadly climate, pithily described as that of two seasons—the wet, when people die of yellow fever in four or five days, and the dry, when people die of pernicious fever in from twenty-four to thirty-six hours. During two seasons the daily burial rate averaged thirty to forty, and that for weeks together.

Then the dishonesty of those in high places—which came out in the subsequent trials—and the misappropriation of funds and wilful waste. "The expenditure," says Dr. Nelson, "had been something simply colossal. One Director-General lived in a mansion that cost over £20,000; his pay was £10,000 a year; and every time he went out on the line he had his *déplacement*, which gave him the liberal sum of £10 a day additional. . . . One Canal chief had had built a famous pigeon-house while I was on the isthmus recently. It cost the Company £3000. Another man

had built a bath-house on the most approved principles. This cost £8000. . . . Five million dollars have been spent in creating a very pretty, well-kept tropical town at Christophe Colomb. Sidings are covered with valuable engines and all kinds of movable plant, which are out in all weathers and going to ruin."

Equally fatal were the physical obstacles afforded by the Culebra Hill and the river Chagres. "The summit cut on the axis of the Canal for about half a mile has an average cutting of 100 metres (330 feet), or 360 feet from the bottom of the Canal. The width of this cut (being on the hillside) at the surface of the ground is about 300 metres (904 feet), and the depth for a few hundred feet on the highest point in this cross section is about 164 metres (538 feet) from the bed of the canal." [1] In 1888 only 34 million cubic metres had been excavated out of an estimated total of 161 million cubic metres, and of the material removed four-fifths was soft and easily worked. The Culebra section—of hard rock—had been scarcely touched, and it was calculated that 470 million francs would still have to be disbursed for the completion of it. An equal amount must also be devoted to the taming of the Chagres, the river that crossed the course of the Canal no less than twenty-nine times. The Chagres, like all tropical streams, is liable to sudden and excessive fluctuations. The original scheme included the damming of the river at Gam-

[1] M. Charles Colné in a paper read before the Franklin Institute, New York, 1884.

boa, and a diversion that should discharge it into Colon Bay. The height of the dam was to be 150 feet above the bed of the river, and its cost about £4,000,000. The diversion channels, 25 miles long, had a dimension almost equal to that of the canal proper, in order to carry off the freshets resulting from a rainfall of sometimes 6 inches a day! Some idea of the body of water such a fall entails will be gained from the fact that in November 1879 the Panama railway was covered to a depth of nearly 18 feet for about 30 miles!

In 1888 M. de Lesseps reluctantly abandoned his original scheme of a sea-level canal in favour of one with locks, which would reduce largely the amount of excavation in the Culebra cutting. But public confidence had been shaken, and after his compulsory resignation of the chairmanship in 1889, the shareholders resolved that the Company should go into liquidation. The liquidators at once took measures to bring some sort of order into the financial chaos, and to organise a new Company. The Colombian Government enacted that the latter should have ten years, dating from 1894, in which to complete its enterprise.

The plans were now drastically altered. By means of an embankment across the valley of the Chagres near Bohio the country between that place and Obispo would be converted into a huge lake, to serve as part of the canal and a reservoir for the storage of flood water. In case of need a second

dam would be added at Alhajuela, 9 miles above Obispo. A waste weir was to carry off the surplus water of the new lake into a special channel; and the lake itself would be reached from the lower levels by four locks on the Pacific side at Paraiso, Pedro Miguel, and Miraflores, and by an equal number on the Atlantic side at Bohio and Obispo. This scheme would entail the diversion of the railway for a distance of 31 miles to skirt the lake; and a total expenditure of over £20,000,000.

Work on the Canal *was never stopped.* At its slackest times more than 1000 men found employment. From 1899–1902 the working force averaged 2200 men, so that the picture of plant and excavations left entirely to the tender mercies of Nature must be written down as an unpleasant fiction.

While the new Company was quietly pursuing its programme the United States had instituted surveys of the Nicaragua-Costa-Rica Canal region, in order to humour the patriotic cry for a States-owned and controlled inter-oceanic canal. In 1899, however, all bills for the construction of a Nicaraguan Canal were rejected in favour of a measure providing for further investigation of the whole question—including the survey of the isthmus—*de novo.* The President, Mr. M'Kinley, acting on powers conferred, appointed a Commission of nine members, which in 1901 recommended the construction of a canal through Lake Nicaragua, with a total length of $183\frac{2}{3}$ miles, the cost to be about £40,000,000.

This alarmed the Panama stockholders, and in 1902 they decided to offer their property and concessions to the United States in consideration of a sum of $40,000,000. Public opinion being then completely reversed by this offer, the President was authorised to acquire for the United States, at a cost not exceeding the sum demanded, all the rights and privileges, unfinished work, plant, and other property, of the New Panama Company on the isthmus, including the railway; to acquire from the Republic of Colombia exclusive and perpetual control of a strip of land not less than six miles wide from the Caribbean Sea to the Pacific Ocean; and to construct a canal of such depth and capacity as would afford convenient passage to ships of the greatest tonnage and draught then in use.

Thus ended the second chapter in the history of the Canal, and France, through the grievous mismanagement in the period 1880–88, "lost an opportunity of acquiring influence in Central America, and upon the American continent generally, which in all probability will never again fall within her grasp."

Colombia had still to be reckoned with. As long as the Nicaraguan scheme was seriously entertained by the United States the Bogota Government showed itself most anxious to concede almost anything that might be asked. But when the offer of the Canal had been made by the Company these professions ceased, and harder terms were demanded. Colombia continued to haggle for conditions that the States

could not grant. Her pecuniary demands were satisfied by a compromise, and her nominal sovereignty preserved by a diplomatic fiction. But before the United States Government could commit itself to so prodigious an undertaking as the completion of the Canal, it naturally enough required a guarantee that its occupation of the Canal territory should be permanent. The offer of the Canal Company having being formally accepted in February 1903, a treaty was signed by the States in the following month, as the result of energetic measures on the part of President Roosevelt, and all that remains to be done at the time of writing these lines is its ratification by the Colombian Government before work on the Canal can be definitely undertaken by the Americans.

The Commission appointed in 1899 rejected the sea-level scheme of M. de Lesseps as entailing a computed expenditure of £48,000,000 for the completion of the Canal. In its place they suggested a modification of the plans laid before the new Company in 1894, which would require an outlay of about £30,000,000.

The Project for Completion

In deciding the dimensions of the Canal the United States Commission considered the future rather than the present types of the world's shipping. Though cargo vessels do not in the main increase their length and beam so rapidly as passenger fast liners, their individual tonnage very sensibly augments from year

to year, since experience proves that large cargoes are handled more economically than small.

The depth of the Canal was therefore fixed at 35 feet throughout, and the minimum bottom width at 150 feet. In Panama Bay the width will be increased to 200 feet, though at high tide there will be a channel 320 feet wide. The side slopes will vary between 1 to 1 in soft earth and 4 to 1 in hard rock. On curves, where more steering room is required, the channel will be broadened in proportion to the diminution of the radius of the curve.

The locks, of which five flights are included in the plans, will raise vessels from the two end sea-level sections to the central stretch, $21\frac{2}{3}$ miles long, extending from Bohio to Pedro San Miguel. This section, which includes the Culebra-Emperador cutting, will have a bottom level 47 feet above mean sea level, so that the two locks at Bohio will give a united lift of some 82 to 90 feet, according to the altitude of the surface of the central reach. On the Pacific side the transference will be made by two locks at Pedro San Miguel and one at Miraflores.

The locks are to be doubled at every step, so as to permit simultaneous travel in both directions, and obviate any total cessation of traffic, in case of repairs to any one lock being necessary. They will have a clear length of 740 feet, a width of 84 feet, and a depth equal to that of the canal over the sills. For the quicker passage of small vessels a subdivision by ntermediate gates is contemplated. All locks will be

founded on rock, walled with concrete, and fed by culverts through which water will rush at a maximum speed of 40 miles an hour—a severe test of the quality of the lining.

It has been mentioned above that the two greatest difficulties encountered on the Canal by the De Lesseps Company were the stemming of the river Chagres and the piercing of the rocky eminence at Culebra. The American scheme for overcoming these obstacles is distinguished by its boldness of design, and the opportunity that it will afford for a remarkable display of engineering skill.

At Bohio the course of the Chagres will be crossed by a dam thrown from side to side of the valley. The effect of this dam must be to pen up the waters until a lake is formed, rapidly increasing its area as it becomes deeper. It has been calculated that, with an annual traffic of 10,000,000 tons, there will be required for the working of the locks an average supply of 1063 cubic feet per second. The annual average flow of the Chagres is about 3200 cubic feet per second, but at the dry season it decreases to less than one-sixth of this amount. The United States Commission therefore decided that the lake should be of such dimensions as to afford storage for 3,654,720,000 cubic feet, the total deficiency during the three months of February, March, and April, in addition to the amount requisite to maintain a channel of a minimum depth of 35 feet. The height of the dam will therefore be such as to withstand a head of 90 feet of water, its

top having an elevation of 100 feet above mean sea level.

As the water collected by the lake would naturally flow off at the lowest point after attaining a certain depth, it has been determined to bar that point—near the head of the Rio Gigante—by a weir, the height of which will be 85 feet above mean sea level. When the water of the lake is even with the crest of the weir it will cover 38½ square miles; but in time of heavy flood, with a discharge 5 feet deep over the weir crest, the area will be enlarged to 43 square miles.

The water pouring over the weir, which is to be 2000 feet long, will pass into artificial channels, connecting a succession of swamps until the neighbourhood of Gatun is reached, where it will once again enter the bed of the Chagres.

The most important feature of this scheme is the great Bohio Dam. At the summit 2546 feet long, it will have a total height above the foundations of 228 feet on its centre line, where the earth-work forming the bulk of the construction is to be reinforced by a masonry core driven down to hard rock. "The earth faces are designed to have mean slopes of one vertical to three horizontal, broken by benches, each 6 feet wide. Although it is necessary to pave only the up-stream face, it is probable that both faces will be revetted with rock spoil from the site of the Bohio locks. The masonry core would be 30 feet thick at and below −30 (*i.e.* 30 feet below sea level), tapering from that

level to 8 feet at the top. The proposed method of construction involves many novel and untried features, the extension of pneumatic work to probably unprecedented depths, and special details in making tight joints between the caissons. The difficulties, very great under ordinary circumstances, will probably be considerably enhanced by climatic and other surroundings."[1]

It is calculated that the construction of this enormous barrier will entail the removal and placing in position of 2,200,000 million cubic yards of material, of which nearly 300,000 cubic yards will be represented by concrete. The cost, £1,210,235, will equal that of the Nile Dam, and the cubical contents of both are about the same.

The creation of the lake will of course enormously decrease the amount of excavation originally estimated by M. de Lesseps. Yet a huge quantity of quarrying will be necessary at the famous Emperador-Culebra cutting, where the bottom of the Canal will still be 286 feet below the natural surface of the ground. To quote Mr. Leigh once more, "From many points of view the Emperador-Culebra cuttings may be regarded as unique in the annals of engineering, for never has the hand of man essayed a task of like character and more striking dimensions. . . . It involves labour necessarily costly and prolonged, and its main interest to engineers centres in the remarkable opportunity which the undertaking will afford for organisation,

[1] Mr. J. G. Leigh in "Traction and Transmission."

methods, and tools specially adapted to the work. . . . The amount of excavation involved in the completion of the cutting is estimated at about 43,237,200 cubic yards, or nearly 45 per cent. of the aggregate of all classes of material which must be removed prior to the opening of the waterway. It is believed that by methods of excavation usually resorted to, the cutting can be completed in eight years, exclusive of a period of two years for preparation and unforeseen delays."

Much of the excavation will be through rock, but the strata of clay encountered will require an equal expenditure in labour, as their unstable nature necessitates the lining of the slopes throughout the entire length of the cutting with masonry retaining-walls, built nearly vertically on a series of broad ledges, rising one above the other on either flank. The Panama railroad, which must be rebuilt for 15½ miles between Bohio and Obispo to avoid the lake, will, after passing the latter town, run for six miles or so along one of the ledges on the east side of the cutting.

Out of the $144,233,258 to be devoted to the completion of the Canal, the 6 miles of deepest cutting will consume $42,000,000, more than the aggregate cost of the Bohio dam, all the locks, the Gigante weir, and the other work to be done between Bohio and Miraflores. Had Nature but omitted the Cerro de Culebra from her scheme, it is probable that for years past vessels would have crossed from ocean to ocean.

At Colon a large harbour will be built to improve the entrance to the Canal and protect it from the "northers" of the Gulf of Mexico. At the Panama end $4\frac{1}{2}$ miles of dredging will be requisite to carry the Canal to the 6-fathom line in the bay.

The time occupied by vessels in passing through the Canal will vary with their size, the permissible speed decreasing with the increase of a ship's tonnage. It has been calculated that, allowing $5\frac{1}{4}$ hours for lockage, the Pacific and Atlantic will be but $11\frac{1}{4}$ to $14\frac{1}{4}$ hours apart, according to the dimensions of the steamer.

The projected Nicaraguan Canal — now finally abandoned—would have had a length of 187 miles between Greytown on the Caribbean Sea and Brito on the Pacific. Of this distance the lake would occupy 70 miles, and the canalised San Juan River an equal proportion. It was proposed to dam the San Juan at Conchuda, and so throw some 50 miles of its course into the same level as the lake—104 to 110 feet above mean sea level. Four locks between Conchuda and an equal number between the lake and Brito were to transfer the traffic from the lower to the higher level.

The disadvantages attaching to this route were: (*a*) the cost, double of that required for the completion of the Panama Canal; (*b*) the great difficulty of controlling so large a body of water as Lake Nicaragua; (*c*) the large number of locks, combining with

the total length of the Canal to make (*d*) the passage of the Canal a matter of at least thirty hours. Under this latter head it may be noticed that though the distance from San Francisco to New York is 377 miles greater *viâ* Panama than by Nicaragua, the duration of the journey by water would be about the same in both cases.

There cannot be the least doubt that the United States have acted prudently in surrendering all ideas of a canal constructed throughout by Yankee capital and engineers, and deciding to bend their efforts to the completion of a work partially carried out by the ill-starred French Companies.

What will be the effects of the perfected Canal on the commerce of the globe it is indeed hard to calculate. But that it will prove an immense stimulus to inter-oceanic trade, by breaching the 9000-mile barrier of the American continent at the most convenient point, is not to be doubted. The States, as controllers of the Canal, will gain an immense strategic advantage, since they will be able to throw their fleet from one ocean to the other as required. Furthermore, all their ports will benefit largely, since those on the west will then command a shortened route to Africa, and those on the east be much nearer the East Asian markets than formerly. In fact, for all practical purposes, Panama will be the great gateway between the East and the West.

Yet the Canal will not command a monopoly of the carrying trade across Central America, since a

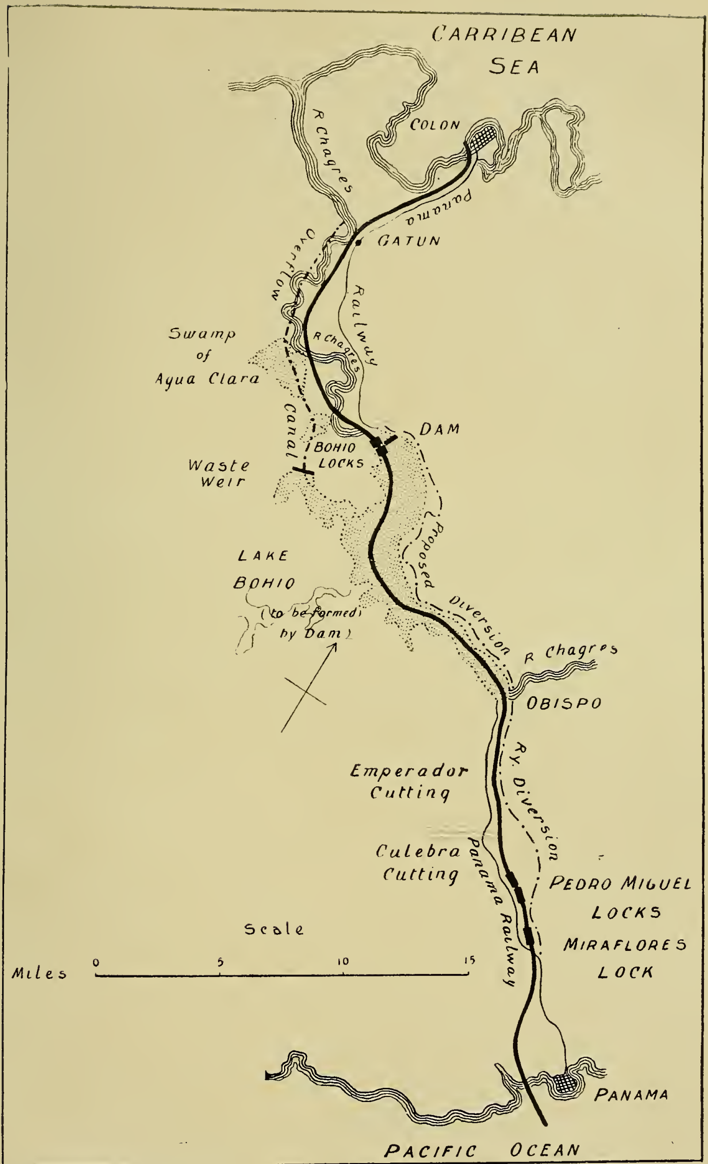
rival is already in the field, and what is more, actually at work.

In the south of Mexico, east of the Yucatan promontory, the two oceans are within 160 miles of each other. The great Cortes, having vainly sought a natural channel, conceived the idea of constructing a carriage road across this comparatively narrow neck, so as to put Spain in communication with the spice islands of the East Indies. He accordingly bought up land on the Coatzacoalcos River and round Tehuantepec—from which the isthmus takes its name—with an eye to profit by the road; which was, however, not actually made until five centuries later, when the discovery of gold in California, and the dangers of travel across the northern prairies, rendered such an undertaking an absolute necessity.

At a later date Captain Eads proposed a railway over which ships should be transported bodily from ocean to ocean, borne on trucks running over several parallel tracks, each furnished with one or more locomotives. The vessel was to be transferred to land from the water by means of a pontoon carrying a cradle furnished with wheels running on six lines of rails. As soon as the pontoon had been raised to the height at which its rails and those on shore were on the same level, the cradle and its ship would be moved from the one set to the other, and all would be ready for the land journey. It is needless to follow the details of the scheme further, as it proved abortive.

In 1895 the Mexican Government completed an ordinary-type railroad across the Tehuantepec Isthmus, from Coatzacoalcos on the north to Salina Cruz on the south. But owing to the lack of proper terminal harbours the traffic on either track was disappointing. At that time Sir Weetman Pearson—head of the London firm of S. Pearson & Son—was engaged in the wonderful harbour of Vera Cruz, described at length elsewhere in these pages. He entered into an agreement with the Government for improving matters in the isthmus; the Mexican authorities undertaking to expend £3,000,000 on the harbours, and an additional £500,000 on the railway; his firm to carry out the contracts and furnish whatever money might be further necessary to put the line in first-class working order. This partnership will last for fifty years, after which period the whole of the property will pass under the sole control of the Government. The latter on its part binds itself not to grant during this time any concession for the construction of other railways and ports within 30 miles of the Tehuantepec works; but it reserves the right of employing any ships of the Company in event of war in consideration of a monthly remuneration; and of transporting coal, troops, and immigrants at reduced rates; mails to be carried free.

The railroad crosses the isthmus at the narrowest part of Mexico, covering a distance of only 192 miles, so that freight received from one ocean will be able to be shipped in the other ocean within the short space



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The American Plan for completing the Panama Canal.

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of twenty-four hours. Owing to necessary windings in places, the road is 50 miles longer than a straight line between the extreme points. In spite of the fact that the country in some parts, particularly on the Pacific side, reaches an altitude of 3000 feet, the highest elevation of the track is but 852 feet above sea-level.

The harbour works are expected to be completed in 1904, when the terminal ports of Coatzacoalcos and Salina Cruz will be converted into first-class sea-ports, accessible in all weathers. At the former place the natural harbour is good, but there is only 15 feet of water on the bar at low tide. Dredging operations are being carried on to give the channel a depth of from 30 to 40 feet. Along the river front quays two-thirds of a mile in length are being constructed. At Salina Cruz very extensive works are necessary, as the port has to be constructed in an open bay, with breakwaters similar to those of Vera Cruz. The Mexican Government intends to make the towns worthy to be called inter-oceanic route stations, and to render them as healthy as possible by a pure water-supply and enforced regulations for the paving and cleansing of the streets.

The Government has granted a concession to Sir Weetman Pearson to construct a line from Ojapa on the Tehuantepec Railway to Alvarado on the river San Juan, which is already in direct communication with Mexico City *viâ* Vera Cruz. There will thus be two ports on the Gulf from which goods can be forwarded to Salina Cruz on the Pacific.

The prospects of the Tehuantepec Railway may be deduced from the following considerations. In the first place, the Tehuantepec Isthmus is 1300 miles north of Panama, and therefore much nearer the trade centres of the United States than the Canal will be. The difference in mileage between certain points by the railway and by the Canal may thus be stated :—

	By Tehuantepec. Miles.	By Panama. Miles.
New York to San Francisco . .	4,925	6,107
New York to Honolulu . . .	6,566	7,705
New York to Hong-Kong . .	11,597	12,645
Liverpool to San Francisco . .	8,274	9,071
New Orleans to Acapulco . .	1,453	3,983
New Orleans to San Francisco .	5,596	3,586

Though Coatzacoalcos on the Atlantic is 800 miles south of New Orleans it is nearer than that town to San Francisco.

Secondly, the sea-to-sea charges of the Panama Railway are about 20s. per ton; of the United States Railways 60s. per ton. It is expected that the transference will be made on the Tehuantepec line for 16s.; and if to this be added 10s. per ton as the cost of the Pacific Ocean journey from Salina Cruz to San Francisco, the shipper will be able to pass goods from the latter town to the Gulf at a total charge of 26s., or but one half of all-rail transit *viâ* Mexico City and Vera Cruz. It is obvious from these figures that the Panama Railway,

even if it reduces its charges, will not compete seriously with the northern route, which, at least until the opening of the Canal—an event not likely to occur for twelve years or more—will obtain the bulk of the ocean-to-ocean carrying trade.

NOTE.—The author desires to acknowledge his indebtedness to two articles published in *Traction and Transmission*, over the signature of Mr. J. G. Leigh, for information about the Project for Completion of the Canal; and to Mr. J. Meldrum, M. Inst. C.E., of Messrs. S. Pearson & Son, for particulars of the Tehuantepec Railway.

CHAPTER XV

HARBOURS OF REFUGE

THE sky is dark and overcast; the wind whistles fiercely; the air is laden with spray. Nature is putting out her strength, lashing the sea into fury against all things that withstand the onset of her foam-crested billows, which rush landwards, heavy with the force gathered in open ocean. The waves hurl themselves again and again on the outer face of the breakwater, and fall back baffled on to their succeeding fellows. Every few seconds the charge is renewed, with as little effect; for the great mass of granite and concrete has been well and truly laid by cunning engineers, well-versed in the methods of curbing the rage of Father Neptune.

Outside all is roar and motion; inside the protecting bulwark ships ride securely, heedless of the miniature wavelets that trouble the peace of the harbour. A few hours ago, maybe, they were breasting the billows, shouldering off the masses of grey water from bow and sides. But now, guided by skilful hands, they have safely passed the narrow entrance and won the shelter provided for them by the foresight of those who are responsible for the well-being of ships.

To deal in superlatives is often risky, but we may

safely premise that among the works of man the most romantic are those brought to a successful issue in salt water. The long list of failures in his struggle with the sea serves but to enhance his brilliant successes. Every time we witness a great storm our thoughts turn to the heroism of Winstanley and Smeaton toiling to fix upon secure foundations light-giving guardians of the coast. We picture again the brave Dutch busy in the breaches in their dykes, desperately hurling down fresh material to stem the threatened inundation of their low-lying plains. The tumbled masses of rock below yonder cliffs remind us how patient and terrible a foe is the sea that can dislodge those monster fragments from their solid bed.

Perhaps we may even spare a thought for the engineers who planned and created the esplanade on which we stand. As being backed by mother earth it probably appeals to our imagination less than the breakwater waging its solitary warfare far to sea. But a consideration of the immense power of the waves, seen in the records of an instrument named the marine dynamometer, will show us how great must be the designing skill, and how thorough the constructive workmanship required to erect a structure that shall for many years defy the elements.

The dynamometer consists of a closed cast-iron cylinder, which can be firmly bolted against a rock or other substance exposed to the violence of the waves. Each end is bored with a number of holes

to accommodate several metal rods that pass right through, and project both ways for a certain distance. To the seaward extremities of the rod is attached a circular iron plate of known area, which, when struck by a wave, drives in the rods, and extends a very powerful steel spring inside the cylinder, at the same time causing leather collars to slide up the guide rods to indicate the amount of extension. At Skerryvore Lighthouse, in the Atlantic, a force equivalent to nearly *three tons* per square foot was registered during a heavy gale in 1845; and on the coast of Dunbar the figures on another occasion rose to three and a half tons. This force was applied instantaneously, of course, with sledge-hammer effect.

The power exerted by a wave on a large surface must therefore be immense. We can, from these records, understand why great blocks are torn from their settings in the face of a breakwater or sea-wall: and why masses of concrete weighing upwards of 2000 tons are sometimes shifted bodily from their foundations. Nor is the sea satisfied with detaching matter at its own level, for on storm-beaten coasts there may be seen large boulders weighing many tons, that have been quarried out of the solid rock at heights approaching 100 feet above high tide-mark.

The designing of harbours is one of the most difficult branches of civil engineering. It is also one of the most important to a country like Great Britain, which depends for its commerce on sea-borne traffic. The value of a large mercantile marine would

be greatly discounted by insufficient harbours; and the same is true in even a greater degree of a powerful fighting fleet, which requires shelters on many points of a coast line where no great commercial activity may be shown. And it so happens that where nature has denied a refuge strategical conditions often demand that an artificial one of great extent and security shall be provided.

During recent years the Great Powers have been very busy with the construction or extension of their harbours.

The French have converted a portion of the sandy Calais strand into a series of fine docks and quays, and greatly enlarged the accommodation at Toulon and Rochelle. The Germans have been busy at Wilhelmshaven. Russia can boast the new harbours of Vladivostock and Port Arthur; Italy that of Trieste. England may point to new works at Portland, Dover, Gibraltar, Keyham, Simon's Bay, and Hong-Kong.

The English harbours named are primarily strategical. Portland Harbour is one of the finest artificial refuges in the world. In 1847 two breakwaters were commenced to close the Bay, on the south and south-east, and completed by convict labour in 1872. The recent works, breakwaters 4465 and 4642 feet long, have been added to secure the harbour from torpedo attack. They consist of rubble mounds deposited in from 30 to 50 feet of water by special hopper barges. The harbour has now three entrances of an

aggregate width of about 1800 feet in the three miles of protecting moles, which enclose 1500 acres of water 30 feet deep at low tide.

At Dover the Admiralty is constructing a Naval Harbour of 610 acres, exclusive of the Commercial Harbour that nestles behind the same defences. The three breakwaters that enclose it measure 2000, 4200, and 3320 feet respectively; and are built of massive concrete blocks, arranged so as to form a nearly vertical wall from the chalk at the harbour bottom to a point 10 feet above high water.

At Gibraltar, works of almost equal size have protected an area of 440 acres. The New Mole, on the south, has been extended for 2700 feet seawards. On the north the New Commercial Mole runs due west for about 4000 feet, and then turns southwards at right angles to its original course. Between the heads of these two moles lies the Detached Mole, which is a good example of modern harbour engineering. Breakwaters in earlier days consisted usually of rubble mounds — heaps of large rough stones thrown into the sea, and left to the consolidating action of the waves. Sometimes on the summit of the mound was built a masonry wall, faced with hard granite. The construction of such a wall proved, in exposed positions, a matter of great difficulty, as a violent storm would often work havoc with the unfinished or scar end. Engineers therefore endeavoured to imitate nature in substituting for cohesive strength in their structures the inertia of

weight of large masses. However tightly bound and cemented small blocks may be, water has a way of burrowing in between them, and splitting them apart. The smaller the block the larger is its surface in proportion to its cubic contents, and as every joint is a vulnerable point in the harness of a breakwater, the reduction of the number of such joints is obviously desirable.

Consequently we find the harbour-builder of to-day handling immense blocks upwards of 50 tons in weight, and laying them in position by means of very powerful cranes called Titans. Steam, improved machinery, and Portland cement have revolutionised harbour construction. At Gibraltar the Detached Mole is isolated from the nearest point on shore by some half mile of water. The usual rubble mound having been formed as a foundation, a box-shaped steel caisson was constructed in England, shipped to Gibraltar, re-erected, floated out, sunk on the rubble mound, and filled in with concrete, so as to form a mass of about 9000 tons well able to resist the roughest buffets of the sea. The caisson measured 101 feet in length at the bottom, and 74 at the top. It was 33 feet wide, and 48½ feet deep.

Having thus provided themselves with an artificial rock from which to commence block-setting operations, the engineers installed a Titan crane. This monster could handle blocks weighing 36 tons at a radius of 75 feet and less; and yet was not the largest of its kind, for Titans are in use which will

pick up a 50-ton block and lay it anywhere within 100 feet of the central pivot.

The Titan is, in general design, a very powerful balanced girder or cantilever, swinging horizontally on the summit of a lofty framework provided with wheels to run on a line of broad gauge. On the one arm are stationed the boiler and winding gear and counterpoises to the weight to be lifted at the other extremity. Beneath the superstructure is a circular roller-path on which it revolves. Gear is provided which communicates motion to the track wheels, and renders the Titan self-moving.

Barges bring the great concrete blocks from the yard, where they are made and kept a long time seasoning, alongside the completed portion of the Mole. The Titan swings round, lets fall its tackle, and soon has the block stacked on the wall behind it ready for use. As soon as the barges are empty the divers descend to the working face of the breakwater to adjust the blocks as the Titan lowers them. The first or lowest course is the longest, that is, it extends farthest horizontally from the Titan, which when dealing with it must take full advantage of its great reach. Each ascending course approaches one step nearer to the steel giant, the top course being just in front of his feet. When a sufficient number of layers have been added rails are laid down, the driver connects up the steam-gear with the track-wheels, and the Titan rolls slowly forward a few paces over the blocks that a short time before were

By permission of] [*Messrs. Stothert & Pitt, Bath.*

A Titan Crane setting 40-ton Apron Blocks at South Shields.

The most powerful Titans have a reach of 170 feet radius, and handle 50-ton blocks.

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being dangled in the air. Meanwhile a second Titan has found room to work back to back with its brother, and the work is pushed forwards in both directions simultaneously, until the last blocks are in position and Gibraltar owns a protection proof against the fiercest gale.

Far away from "Gib," in the Gulf of Mexico, a wonderful harbour has just been completed at Vera Cruz, "the great mart of European and Oriental trade, the commercial capital of New Spain." The spot is historically famous as that at which Cortes and his brave little army landed in 1519 to commence the conquest of Mexico. The roadstead was until recently notorious as one of the most dangerous on the American coast, for the *norte*, or "norther," sweeping the waves across the Gulf, drove many a vessel to destruction on the coral reefs that partially encircle the bay. "During a norther which blew in the year 1851, thirteen ships were wrecked in the Vera Cruz roadstead. This was no doubt an extreme incident, yet every ship entering Vera Cruz during the norther season was constantly exposed to the same fate. It may be said that eternal vigilance only was the price of safety. Every ship during the dangerous season, before the portworks were commenced, was obliged to keep up full steam in order to be able to put out to sea at a moment's notice on the first indication of an approaching norther, and had, moreover, even under favourable conditions of weather, constantly to keep its propeller gently working in order to ease the strain

on its moorings. In addition, all loading and unloading of merchandise had to be done (when it could be done at all, and that was in absolutely fair weather only) by means of lighters, as there was no pier with sufficient depth of water alongside to enable ships to use it for loading or discharging their cargo. A very slight breeze was sufficient to stop all work in the port. The loss of time by this primitive method of handling cargoes was only one drawback, as the item of expense due to repeated handlings, loss and damage to the goods, was also very great. When, owing to hurry or the necessity of sailing at a given time, a captain persisted in unloading his vessel when a moderate breeze was blowing, it was no uncommon occurrence for the cargo, when craned over the vessel's side, to go to the bottom of the sea instead of on board the lighter. In a word, the visit of a vessel to Vera Cruz was a source of anxiety to its captain, its owners, and the consignees of merchandise, until the latter was safe on land."[1]

But Vera Cruz had long been recognised as *the* port of Mexico on the Atlantic. To it railways ran from the capital far away in the mountains *viâ* Tlaxcala, Puebla, Cordoba and Xalapa. Under the leadership of President Porfirio Diaz, the Maker of Mexico, the spirit of modern enterprise has been awakened in the land of the Aztecs. As soon as social and financial order had been restored by President Diaz, public attention was turned to the improvement of the port.

[1] From a descriptive Memoir of Vera Cruz Port Works.

In 1882, Captain Eads, the gifted American engineer, submitted plans for checking the fury of the "norther"; and in the same year the first block was laid in the rear of the old Castle of San Juan de Ulua.

The accompanying plan will explain the positions of the various parts of this great undertaking, which in connection with new quays and piers cost £3,000,000 ($15,000,000). The coast-line faces N.N.E. To the north lies the coral reef of Gallega, on which rises the castle of San Juan; to the east the Hornos reef, to the west the reef of La Caleta.

Captain Eads and subsequent contractors built the North Mole, running north-west from San Juan; and that, together with the line of "random blocks" laid on the north-west, constituted the sum total of operations in 1895, when Messrs. S. Pearson & Son, of London, signed a contract for the completion of the protective works, and the conversion of Vera Cruz into a first-class artificial port, equal to any in the world, and equipped with every modern facility.

The breakwaters include one on the north-west inside that of Don Agustin Cerdon referred to above, another on the north-east to the east of the Gallega reef, and a third on the south-east, extending from the shore to the Lavandera reef. These close the harbour to the sea, except between the San Juan Castle and the north end of the north breakwater, and at the port entrance between the north-east and south-east breakwaters.

The north-west breakwater was completed by de-

positing a rubble mound inside the random blocks already in position. Trestles (of creosoted piles) were first built 16 feet above low water, to carry trains laden with stones. As fast as the mound reached low-water level, it was topped with two courses of 35-ton blocks laid by a Titan; and these, after being allowed to settle for two "norther" seasons, were capped with a concrete coping. This breakwater is 1200 yards long. The north wall, which it joins, is a concrete monolith laid on the top of the Gallega reef for 550 yards.

The north-east breakwater afforded the most difficult part of the undertaking, since on it the storms burst with full violence. On one occasion a Titan crane, weighing over 360 tons, was carried away by a stiff norther and flung into the harbour, from which it was recovered after several unsuccessful attempts. The seaward face of the wall is protected by a large number of concrete blocks thrown in at random. The rubble foundation, 26 feet deep, and rising to about 10 feet below low-water level, was carefully levelled by divers and surmounted by three courses of sloping blocks and a concrete coping. Its length is about 800 yards, and its average width 34 yards.

The south-east member is almost entirely rubble work, with a single line of blocks at its apex. This wall is nearly 1000 yards long. As a further means of defence against the prevailing south wind, the plans included an inner protection about 1080 yards inside the south-east breakwater, which forms part of, and

projects at right-angles to, the town quay. The portion of the harbour between these two protecting walls is used for the anchorage of small craft.

The harbour was cleared to a depth of 26 feet by means of large and powerful dredgers, and an extra depth of 5 feet given to a belt extending from the harbour entrance to the main town quay. Some of the sand dredged was employed to reclaim the ground on which the quay now stands, 430 yards from the natural low-water line.[1] For the construction of the quay a trench was dredged, and a rubble stone foundation formed and carefully levelled by divers. Upon this the same men built up concrete blocks to a height of 2 feet above low water, from which level solid concrete and Norwegian granite raised it to a convenient altitude for shipping. A number of piers for shipping extend into the harbour at right angles to the town quay: one much larger than the rest, 400 yards long by 108 yards broad, affording room for seven of the largest vessels that visit Vera Cruz to unload at the same time. This pier was built in the same manner as the quay—by first raising a solid wall round its outer edge, and then filling the interior with sand pumped from the harbour. Eight railway tracks traversing the quay serve to convey merchandise to the Mexican trunk lines.

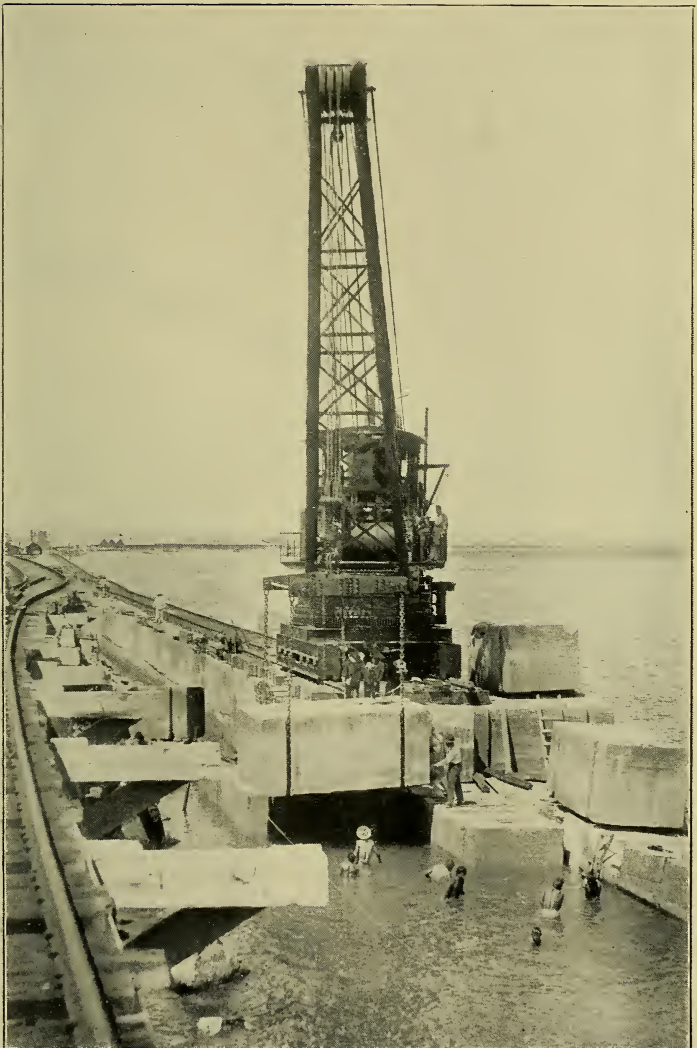
"As the shipping interests of Vera Cruz increase

[1] During the dredging operations iron and stone cannon-balls, bayonets, sabres, pistols, arquebuses, and doubloons were constantly being brought up, silent reminders of the heroic days of the Spanish conquerors.

(and assuredly they will do so rapidly), greater wharfage, quayage, and storage than the present liberal facilities in this respect will be necessary, and here again the foresight of the Government has been equal to the occasion, for sites have been provided for the construction of a practically indefinite number of new quays and customs warehouses.

"Finally, the terminal company, which is now being formed, and which, it is believed, will consist of the four railway companies operating into Vera Cruz, will provide such facilities, under Government supervision and control, that in a short time from now it will be no unusual thing for ships to discharge 1000 tons of freight per working day."

So many references have been made in the above pages to concrete blocks that a visit to the yards where they were made will be interesting. The three yards were 1¼ miles long. In them, on concrete floors carefully levelled, stand rows of great boxes with removable sides. Small tramways running over the rows convey in skips the concrete—one part of pure Portland cement to five or six parts of broken stone and sand. All day long gangs of men work at the mixing machines where the concrete is made for pouring into the box-moulds from the laden skips. The moulds are so many hungry maws, each the height of a man, and some a dozen feet long by 6 broad. When full, the concrete is allowed to solidify until it is firm enough for the box walls to be removed to some other part of the yard, leaving



By permission of] [*Messrs. S. Pearson & Son.*

A Giant Crane laying 35-ton Blocks on one of the Breakwaters at Vera Cruz Harbour.

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the giant bricks to harden until a great Goliath crane rolls overhead, snatches them up, and stacks them in readiness for transference to trucks and barges. As we read that 3000 tons of Portland cement were always kept in stock, the total weight of the contents of the yards may be imagined.

Besides the artificial blocks great quantities of natural stone were required for the port works. The nearest quarries of suitable stone were at Peñuela, 60 miles distant on the Mexican Railway. Special arrangements having been made for a regular stone-train service, as many as 450 tons of stone were in busy times transported from the quarries to the harbour every day. Large cranes, air-compressors, pneumatic drills, crushing machinery, and houses for the accommodation of workmen had to be erected in the quarries, a special water-supply laid on, and several miles of track put down. To detach sufficient quantities of rock, blasting on a large scale was resorted to. On one occasion 40 tons of dynamite and powder exploded simultaneously, and broke away a mass calculated to contain 200,000 tons. At another of the large blasts the people of the village had assembled to witness the explosion and be included in the photograph taken after each important "shot." Some minutes after the explosion the people ran to the face of the quarry to see the effects, and encountered the poisonous gas generated by the explosive, which, owing to the sultriness of the weather, had not been dissipated, and hung over a considerable

tract round the quarry. As soon as the crowd reached the gas-laden air-stratum they fell unconscious. Out of eighty-three persons dangerously affected no less than twenty-six died; and, as though to heighten the tragedy, a small band of Rurales, or police, who had galloped to the rescue, were also overpowered, two of their number and all their horses fatally. Such an occurrence is probably unique among the annals of rock-blasting. It supplies the one dark episode in the bright chapter of a great work brought to a successful conclusion.

As a result of the fine contract carried out by Messrs. S. Pearson & Son a vessel can ride out the most furious "norther" in complete safety. Vessels moored alongside modern piers furnished with proper mechanical equipments can discharge their cargoes at all seasons directly into railroad cars at a fraction of the cost of the old system, and embark goods sent down to the port from all the railway-fed depôts in the Mexican Republic. The town, covering ground once scourged by the dreaded *vomito*, is now traversed in all directions by large sewers and water-mains, the former discharging through a pipe built in the north-west breakwater into deep sea beyond the Galega reef, the latter deriving their supplies from the Jamapa River. It is significant of the spirit animating the Mexican Government that it willingly sanctioned the great expenditure necessary to complete these important sanitary works, and with commendable foresight has made provision for a much larger

population than at present inhabits the port. The time is not far distant when Vera Cruz will become the Brighton or Margate of Mexico, as well as its Liverpool. Here the jaded citizen of the capital will fill his lungs with the fresh sea breezes, bathe, row, stroll on the breakwater, watch the cosmopolitan crowd that is to be found in a busy seaport, or visit the antiquities of the castle of San Juan. And he will praise the Government when he looks round on the great portworks for having placed Mexico a step or two higher on the ladder of Progress, up which she is steadily climbing.

CHAPTER XVI

OCEAN LEVIATHANS

In 1858 the genius of Brunel sprang a wonder upon the world. The monster steamship constructed at Millwall from his designs, by Mr. Scott Russell, was not merely an advance upon all that had gone before, a Gulliver among pigmies; she was an anachronism.

One of the first liners to be built of iron, which was but slowly superseding wood, and to be driven by the newly developed screw, combined in this case with powerful paddle-wheels, the *Great Eastern* was also a sudden expansion in dimensions and capacity which held the record for nearly fifty years. Yet she was doomed from her very inception to be a gigantic failure, the frequent fate of enterprises born before their due time.

Her keel was laid on May 1, 1854, and after three years' labour, during which 30,000 iron plates were fastened upon the hull by means of 3,000,000 rivets, the great ship was ready to be launched in November 1857. Owing to an ill-advised attempt to retard her motion down the slips, the chain-winding machinery gave way and the launch proved abortive; but she was successfully floated in 1858, and took her trial trip down the river and round the coast. Opposite

Hastings a case-pipe feeder burst, causing some loss of life among the crew, and doing local damage to the extent of several thousand pounds, one funnel being blown 50 feet high into the air. The vessel was otherwise unaffected by the shock, was found to be rigid and steady in a heavy sea, and finally put into Portland for repairs.

In 1860 her maiden voyage to New York, where she received an ovation, marked the beginning of an era. For though years elapsed before engineers again dared to project anything approaching the *Great Eastern* in size, it had been conclusively demonstrated that an iron steamship of vast proportions, laden with passengers and cargo, could, in spite of all prophecies to the contrary, triumph over the perils of the Atlantic and make good time as a mail carrier. Her very faults of design have been an example to guide inventors towards the masterly lines of our modern "ocean greyhounds."

The *Great Eastern's* accommodation was conceived upon a scale of magnificence hitherto undreamed of. Between uprights she was 680 feet long, but her upper deck gave 12 feet extra length; and her width of 82 feet 6 inches was expanded by the platforms of the immense paddle-boxes to 119 feet. In height she towered 60 feet above her keel, half of this being submerged when loaded, though she drew only 20 feet of water in ballast. Five great funnels 100 feet high, and six lofty tapering masts, fitted with square spars that carried an enormous spread of canvas,

rose above the massive hull and rendered her the most imposing vessel that ever rode the seas.

Her internal arrangements were worthy of this majestic exterior. She was built upon the cellular principle, that is, she consisted of an inner and outer hull, both iron-plated, some 2 feet 10 inches apart, up to 3 feet above the water-line; and the interior was divided into nineteen separate compartments, twelve of which were water-tight and the others nearly so. Her principal saloon was 100 feet long, 36 feet wide and 13 feet high, the whole centre of the ship being given up to saloon and cabin accommodation, carefully protected from disturbing noise or vibration of the engines. Fittings and decorations were on the most lavish scale, initiating the luxurious appointments of the present day.

Eight hundred first-class passengers were provided for, 2000 second-class, and 1000 third-class; while, in case of emergency, she could pack 10,000 troops on board without restricting their ordinary space for quarters. The ship's complement was 400 men all told, and the coal-bunkers carried 12,000 tons (enough to take her to Australia or India and back without re-coaling), besides the 6000 tons of cargo to be stowed in the holds.

This immense weight had for motive power ten boilers, weighing 50 tons each, divided among separate sets of engines, some of which worked a screw-propeller 25 feet in diameter, while the others turned the gigantic paddle-wheels, each 56 feet across,

From a photo lent by] [*the White Star Liners Co.*

A Stern View of the "Celtic" in Dry-dock.

This huge vessel is inferior in size only to her sister ship, the *Cedric*. Her displacement is 20,900 tons. Besides 15,000 tons of cargo she carries 3,000 passengers. The size of her immense twin screws may be gauged by comparison with the man in the foreground.

[*To face p.* 310.

and weighing 185 tons. Twelve tons of coal per hour were consumed, but the speed hardly exceeded 14 knots, though a considerably better result had been anticipated. The i.h.p. of the paddle-engines was 3000 normal to 5000 under full pressure, and that of the screw-engines could be raised from 4000 under ordinary pressure to 6500 when desired.

We need not follow the *Great Eastern's* eventful history, which will be fresh in most minds. How one steamship Company after another collapsed in employing her for her original purpose; then the useful work which she did for years as a cable-laying ship between England and America, India, &c.; finally, her most unqualified success, when she was chartered as a show at Liverpool. In 1886–87, her hull and machinery being still quite sound, though somewhat "off colour" with long neglect, she was sold piecemeal. An auction of scrap-iron and old timber! Such is the last scene in which figures this extraordinary feat of marine engineering, after thirty years of such vicissitudes as surely no other ship has ever experienced! Nor are any of the creations of our own day likely to pass through so romantically chequered an existence.

The failure of Brunel's *Great Eastern* as a commercial speculation gave pause to other inventors for many years. Modest liners of 7000 to 8000 tons continued to bear the ocean traffic, and not till 1889 was a displacement expressed in five figures again attempted. A re-action, however, in the direction

of large passenger ships has set in and grown steadily since the *City of Paris*, with her 10,670 tons, found favour in 1889; and upon the memorable appearance of the *Oceanic* in 1899 the *Great Eastern* was at last actually exceeded both in length and tonnage.

Most of the great express steamers, to whatever nation they belong, are subsidised by their respective governments to be used as swift cruisers in time of war. They are, therefore, so constructed that the concussion of heavy artillery may not endanger their stability, while the double bottom and water-tight compartments reduce the results of any accident to the hull to a minimum. The framework of these grand liners, which bear to and fro such a precious living freight, is as massive and rigid as that of a man-o'-war; and where iron was employed a few years ago we now find castings of the finest tempered steel, nickel, and bronze. Only the best and most modern materials and appliances are used, everything being brought from year to year most rigorously "up-to-date." And every measurement to the minutest particular, every line or curve of framing or plating, every detail of weight and form required for the interior or fittings, is calculated and worked out on paper before the keel of the new vessel is laid upon the building-slips.

The first process undertaken in the shipyards, therefore, after the draughtsmen's designs and computations have been completed, is the drawing or *scriving* of the proposed vessel's frame to the exact dimensions

of the matured plan. This is done in a shed or loft whose floor is an immense scrive-board, upon which the precise form of every frame in the ship is sketched to scale, and full-sized moulds or shapes are prepared. Near at hand is an iron platform with furnaces attached large enough to contain the whole of a ship's rib, though it may be over 60 feet long. The frame and bars being heated till malleable, are drawn from the furnace on to the iron floor and there bent into the required shape between pegs previously arranged. But before this final bending the frame has been punched for rivets, and cut to the right length, and frequently its edges have been bevelled while it is hot. The punching, shearing, and bevelling machines are therefore also arranged in close proximity to the furnaces and platform. The angle-bars are similarly punched and finished. The beams are prepared in the same fashion, their holes punched, and knees or angles formed at the ends, after which they are bevelled and curved.

By this time the keel has been fashioned and laid at the bottom of the building-berth, other keelsons being laid parallel with it and girders or stringers between them. As the ribs are ready they are brought to the slips and riveted each into its appointed place transversely to the keelsons; the beams (or horizontal frames) overhead holding the outer framework in shape, while wooden *ribbands* are bolted temporarily to the frames to "fair" the whole structure to its correct form. The water-tight

bulkheads, that is, the partitions which divide up the interior of the ship into compartments, having been worked elsewhere, are also brought up and adjusted, helping to give strength and rigidity. Most of them are placed across the hull, which is, however, also divided longitudinally for a great part of its length.

The *framing*, or first part of the construction, may now be considered complete, the whole outline of the vessel standing ready in skeleton for the second operation of *plating*.

The huge iron or steel plates—often 30 feet in length—which, attached to the ribs, form the *shell* plating, and to the beams the *deck* plating, have meanwhile been cast from moulds or templates previously made of the exact size and marked with holes corresponding to those in the framing. The position of the holes being transferred from the mould to the plate, they are punched out and the edges of the plate then sheared. The edges and butts have also to be planed and the rivet holes countersunk; while in some cases the plate must be bent before use. This is done in a machine containing three rollers, two of which receive the plate between them; the third roller is then raised (or lowered) against the free part, till its pressure—several times repeated—gives the desired curve without any reheating being necessary. Some shipbuilders also treat the edges of the plates by a system called "joggling," for which special machinery is provided, which bends them to overlap in such a manner that no strips of lining

metal are required. Thus a saving is effected both of labour and of extra weight in construction.

The plate now is ready for incorporation into the growing vessel. It is lifted to its place by mechanical power, the red-hot rivets are dropped into their holes, and a few blows of a riveting hammer spread and secure their ends. Plate by plate the outside of the vessel is covered with its metal skin; the edges of the plates are minutely faired and caulked; the inner hull, or false bottom, is similarly treated; then the beams receive their complement of plating and the decks spring into existence. The shell is complete, and awaits its motive power and interior fittings.

But we will pause a moment to consider the means by which these various processes of manufacture have been carried through. Hand-worked machinery is rapidly being superseded by wonderfully ingenious and powerful machines run either by steam-engines, by hydraulic or pneumatic power, or by electricity. A combination punching and shearing machine is generally employed, having gaps[1] deep enough to take half the width of the largest plates required. The plate (often supported by chains) is mechanically fed through the gap, but two or three workmen may

[1] To explain the word "gap," it should be stated that the machines for punching, riveting, &c., resemble somewhat in shape a common fret-saw, the light framework being replaced by castings of enormous strength. The gap is the distance between the tool (which occupies the position of the jaws gripping the saw) and the inner side of the back of the bow. The gap of a fret-saw is rather more than a foot.

be needed to guide it and to regulate the distance of the holes, which are stamped out by the punch falling sharply against a die.

Certain machines working horizontally are used for angle-bars and beams; therefore they do not need a wide gap, and are often combined with an apparatus for bending and straightening the beams and bars, and with shears for cutting angles. Farther on we see one of the multiple punches which can stamp forty-seven holes at a time through $\frac{7}{16}$-inch plates, most valuable for tank-work, pontoons, and so on.

For all large and heavy work hydraulic power is greatly in request throughout those countries whose winter cold is not severe enough to impede its use. We therefore find it much employed in English ship-yards for such operations as punching man-holes, flanging plates, or hoisting and riveting large superficies. One of these heavy hydraulic presses can do flanging and joggling, and also punch manholes 21 inches by 18 inches through plates $\frac{3}{4}$ inch thick. Another punches $1\frac{1}{2}$-inch holes in $1\frac{1}{2}$-inch plates 36 inches from the edge at one end, while at the other end it shears similar plates 33 inches from the edge between two steel plates set at the required angle; and an arrangement in the body of the machine enables it to cut channels and tees, or to chop through angle-bars 6 inches by 6 inches by $\frac{3}{4}$ inch in dimensions.

Yonder massive machine surmounted by huge wheels is equally versatile and still more powerful. It quietly bends cold iron beams from 12 inches to

16 inches deep, works a big horizontal punch, and with two sets of shears cuts angles and notches to any section. This one with 42-inch-deep gaps can stamp two holes 1 inch wide through 1-inch steel at each blow; and the other with two gaps 48 inches deep punches rivet holes and cuts notches in stringer-plates 10 inches by 8 inches by $\frac{7}{8}$ inch.

Not far from these is the long plate-edge planing machine, which takes an easy cut off a 2-inch plate, planing 24 feet at a stretch. Those long arms with drills operating from them are the counter-sinking machines, used in groups that they may get to work simultaneously upon the same plate in order to save time, as the greater proportion of rivet holes require this treatment. We notice in passing that the heavy bevelling machines, which have to manipulate the bars or angle-iron while hot, are mounted upon rails to facilitate their being run up to the mouth of the furnace.

The plate-bending machines already mentioned are still more elaborate in structure, and consequently very expensive; indeed, they may cost anything up to £5000. Whether working horizontally or vertically they have to be extremely powerful, the rollers often needing to be braced by strong girders carrying intermediate rollers lest they should be buckled themselves. Those made for straightening out plates (up to 8 feet wide by $1\frac{1}{4}$ inches thick) consist of several rollers, while that which prepares the plates to cover masts rolls them into a complete cylinder which is

removed by being drawn off one end of the upper roller. There stands an hydraulic keel-plate-bending machine, which can curve both sides of a keel-plate at the same time. And any of these various machines can be fitted with hydraulic cranes, &c., to handle the plates.

Smaller, lighter tools, manipulated by separate workmen, may also be driven by hydraulic power with the greatest advantage.

Hydraulic riveting machines are now almost universally used in British ship-yards. These perform their work of burring the heads of rivets by the irresistible power of water pressure, which slowly moulds the free end of the rivet as soon as the jaws of the machine have been brought in position so as to grip the rivet longitudinally. The use of hydraulic riveters, which can be applied to the major part of a ship's frame and plates, effects a saving in cost of 30 to 40 per cent., and the work is done better than by hand.

In America preference is given to the pneumatic riveter; a small tool, which, under an air pressure of 100 to 150 lbs. per square inch, delivers several hundred blows a minute on the tail of the rivet, with a force and rapidity which soon spreads the metal. These tools, being light enough for a workman to carry easily in his hands, are very convenient in many ways, but at present have not found much favour on this side of the Atlantic. In certain of our ship-building yards, however, we find pneumatic riveters,

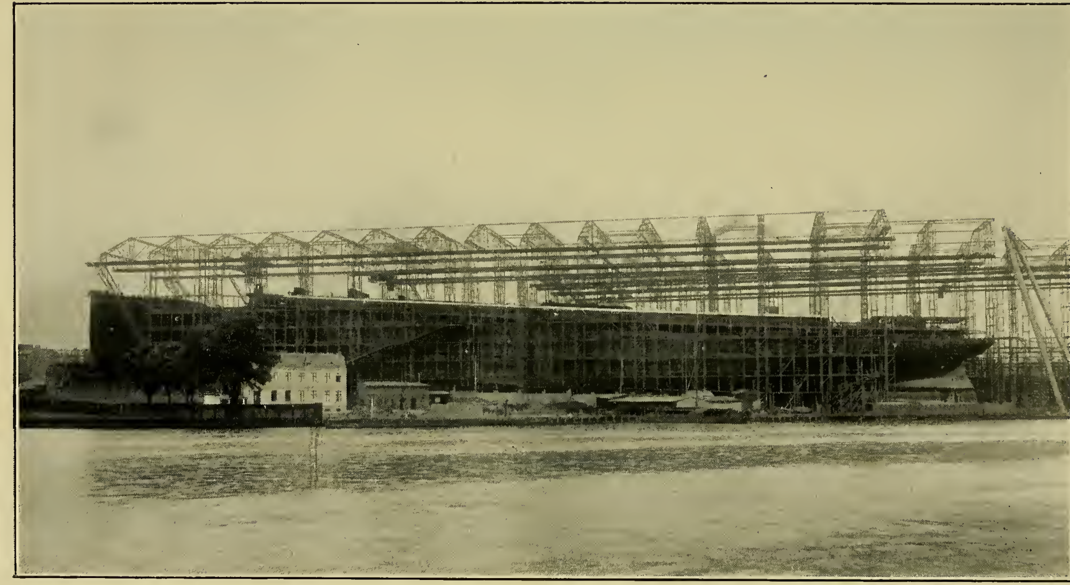
caulkers, and chippers coming into greater use, mainly on account of their portable character, which enables them to be applied quickly to their work. In some cases a pneumatic holding-on hammer is combined with the riveter, though as a rule the holder-on is separate.

Punching, boring, deck-planing, &c., may be also carried on pneumatically, some large drills being in use, but electrically-driven tools seem preferred for these and similar operations.

To deal with the enormous expanse of the modern Argo, and the very large and heavy plates now used for its outer covering, correspondingly gigantesque plant is being devised. Huge revolving derricks worked by electricity lift the heavy portions and install them in their place. At the Newport News yard in America, a cantilever crane, each arm extending 89 feet from the centre (and able to deal with weights of from 4 tons to 12 tons according to position), moves on a trestle 735 feet long. Messrs. Harland & Wolff use a travelling gantry, first designed for the *Oceanic*, which strides across the vessel under construction, and runs on rails laid parallel with its bed; this is provided with three traversing-cranes, and four 4-ton swing-cranes to facilitate operations. Many of the shell plates in the *Celtic* and *Cedric* weigh 3 to 4 tons, and larger pieces of the ships—such as the stern frame—weigh over 50 tons. The famous Vulcan Works, Stettin, hoist their big fittings into place with an enormous "shear-legs" crane, whose

chain-tackle, strong enough to move 100-ton guns if required, can readily deal with such items as pumps, shafts, funnels, boilers, and masts. Some constructors raise a colossal framework to form the building shed, upon the sides and under the roof of which both fixed and movable cranes are arranged to carry and deposit materials, or to support machines and tools.

All such shipbuilding plant is very costly to set up, and the machines are expensive to keep in order. However, the economy in labour, and the increased rate of output rendered possible make it worth while to incur the expenditure. For though the largest-sized ships are found to require a greater proportionate outlay on construction than smaller ones, they are much cheaper to run; all such expenses as loading, coal consumption, and harbour charges falling less heavily when divided over a large cargo. So the tendency of the epoch is to increase the size of vessels year by year. This fact is being brought home even to the most conservative dock owners, and the movement towards widening and deepening harbour and dock accommodation is nearly universal. Both at the mouth of the Mississippi and in New York the entrances are being dredged for a draught of 40 feet, and those European docks which, like Southampton and Hamburg, have kept abreast of the times, are attracting the most flourishing trade. It has been calculated that within the half century our principal liners will measure 1000 feet in length by



From a photo by the] [*Norddeutscher Lloyd Co.*

The "Kaiser Wilhelm II." in the Shipyard.

The two-storey house in the foreground is dwarfed by this 700-foot ocean racer.

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100 feet in breadth, and draw over 30 feet of water.

The White Star Company and the North German lines have, during late years, become rivals in running ships of unusual speed and capacity. Building against each other, they have succeeded in producing veritable floating palaces. There is, however, a fundamental difference in the working principles to which each pins its faith.

Every half-knot gained in speed means an enormously higher coal consumption, since the resistance offered by water to a body moving through it increases more rapidly than the resultant velocity—practically the resistance varies as the square of the velocity. Hence, to double the speed it would be necessary to quadruple the impelling force, and engines of eight times the power would be required—that is, the motive energy must be increased in ratio with the *cube* of the velocity. For example, the engine-power producing 15 miles per hour would have to be twenty-seven times greater than for 5 miles per hour.

The Cunard "fliers" *Campania* and *Lucania*, which till recently held the record for swift Atlantic passages, make 22 knots with 28,000 horse-power; but to get two additional knots per hour 48,000 horse-power would be necessary, and the addition of 290 tons of coal to the present 460 tons consumed per day. German enterprise is bending all its energies to solve the problem of how to add this extra speed without

swamping profits by the initial cost and fuel bill of such powerful engines. The English-speaking company is inclined to spend less on despatch, and to make their gains off large freights and lower fares.

In 1897 the *Kaiser Wilhelm der Grosse*, with a length of 680 feet, and a gross tonnage of 20,880 tons, was the "biggest thing afloat," and her record speed of 23 knots wrested from England the "blue riband of the sea." But the *Oceanic*, measuring 704 feet from end to end, and of 30,000-tons displacement at load-line, was even then upon the stocks at Belfast, and her maiden voyage was watched with exceptional interest. She was built to be a mail and passenger steamer of the finest type and largest size, and soon proved herself to combine speed, steadiness, and comfort with her immense capacity.

The Hamburg-American line replied with the *Deutschland*, launched in 1900, at 16,500 tons, which made the record passage to New York of 5 days, 7 hours, 38 minutes, doing as much as 23·51 knots an hour. The *Kronprinz Wilhelm*, of the North German line, runs her closely with 23·21 knots per hour on occasion.

Meanwhile Messrs. Harland & Wolff's building yard at Belfast was exerting itself to outdo even its former triumph in size—the *Oceanic*—by producing her giant sister the *Celtic*, and subsequently the *Cedric*. In emulation of these the Vulcan Company at Stettin has followed up its first *Kaiser Wilhelm* by a second of

the name which is to surpass (so we are assured) every previous marvel of marine architecture.

Largest of all vessels ever built is the new twin-screw steamer *Cedric*, with gross tonnage of 21,000 tons (the *Celtic* being the first to exceed 20,000 tons), and a load-line displacement of 37,870 tons. The *Oceanic* is luxurious and rapid, her speed averaging 21 knots per hour, but the *Celtic* and *Cedric* were designed as combination ships, adding huge cargo-carrying capacity to comfortable passenger accommodation for those whose desideratum is a moderate charge. Externally they are very striking vessels, but their immense size is so masked by perfect proportion and graceful lines that it can only be appreciated when in comparison with others.

Standing on the captain's bridge of the *Cedric*, we gaze dizzily down to the keel 100 feet below[1]—an elevation comprising no fewer than nine decks—and endeavour to realise that in full length and width the great structure measures 700 feet by 75 feet (5 feet wider than the *Oceanic*). Then the eye is gradually carried upward by the four tall masts, and turns almost with awe upon the pair of monster funnels, 15 feet 9 inches by 12 feet in diameter, towering 120 feet above the top of their fire-grates. Eight boilers supply steam for working the Harland & Wolff quadruple-expansion engines of 14,000 horse-power, which, being perfectly balanced and driven at a medium speed of 17 knots, not only consume less

[1] This only possible in dry dock.

coal, but almost do away with the vibration which has such a disagreeable effect in very fast steamers.

First-class accommodation is all amidships, on the upper-bridge and boat decks, the sitting-rooms forming an imposing suite both in size and in style of decoration. The splendid dining-saloon on the upper deck, superbly illuminated through a domed skylight, its panelled walls embellished by deep mouldings and alabaster frieze, its ceiling brilliant in white and gold, extends the whole breadth of the ship, and will seat over three hundred guests at once. The library—dedicated chiefly to the ladies—is a luxuriously furnished apartment, cosy chairs and lounges, writing-tables, rich pile carpets, carefully screened lights, and a perfect system of ventilation, providing the acme of comfort. A little way removed is the spacious smoking-room, its walls more soberly and appropriately hung with embossed leather, and its plenishings all that the heart of man can desire.

There are single-berth state-rooms (a rare convenience), ordinary state-rooms for two or more persons, and suites consisting of bed-, sitting-, and bath-rooms for families or those who desire privacy. Small adjustable tables, and square windows with screw ventilators are special features in the bridge-deck chambers.

The second class has corresponding accommodation aft, on the upper and bridge decks, almost equally handsome and convenient in its appointments, with bed-rooms, bath-rooms, &c., all of the

latest type. While the third class passengers are domiciled upon the upper, middle, and lower decks, either in separate cabins or in open berths little inferior to what was the highest-priced accommodation a few years ago. For these also are prepared a series of comfortable dining, sitting, and smoking rooms, and the ventilation (by a system of electric and steam fans), bathing facilities, electric lighting, and so on, are—as elsewhere—ordered upon the most approved principles.

Each class of passengers, and the ship's own company has its entirely separate equipment of cuisine; and there are well-found quarters for the crew, who number some 350. Of these about 100 men are employed in the engine department below decks, and nearly twice as many to serve the visitors in various capacities, the rest being deck-hands.

After a stroll along the promenades, and a rest beneath the snowy awnings which make cool retreats from the mid-day sun, we pass from one storey to another by means of broad stairways and along corridors where the feet tread noiselessly and securely upon patent rubber flooring, in artistic designs, and descend to what may be termed the "business premises" of this great marine hostelry. Again we encounter fresh marvels at every step, till there is no more spirit left in us to put another question, and no words can hope to convey the impression left on our mind of magnitude, of mechanical force, of almost limitless foresight and efficiency. How have

the dry bones been clad, the echoing compartments been filled, since we watched the skeleton of the mighty fabric rise with clang of metal upon metal! What thousands of tons of fittings, and furnishings, and every manner of provision, have been hoisted into her and bestowed among her numerous decks before this Queen of the Seas took her first trip westwards as one of the links of empire!

Amidships, its distribution carefully calculated to preserve balance and minimise strain upon the hull, the machinery which provides motive-power for this vast dead weight is situated. Here are the great steam-engines with all their appurtenances, to the untrained eye a bewildering confusion of wheels and cylinders, cranks and rods; the boilers and their supply tanks; the exhaust-pipes and ventilators; the succession of coal-bunkers, arranged to form a protection round the engines which they feed. To explore the length of the massive driving-shafts which convey the engine's energy from the centre of the ship to the propellers at the stern would be a journey in itself.

Incidentally we are introduced to some of the auxiliary engines for steering, pumping, and ventilation; to the electric plant; to the system of telephonic communication, and the wireless telegraphy office. And forming the very basement of the whole building, between the two skins of the hull, lie—rather to be guessed at than seen—the huge water tanks; tanks to hold hundreds of tons of fresh water, tanks

to supply the boilers, and the water-ballast which trims the ship and can be periodically increased to compensate consumption of coal and provisions during the voyage.

Glance in passing into the extensive holds crowded with cargo, which is let down from above by cranes and winches attached to the decks. That massive door guards the strong room wherein all valuables are deposited beneath the captain's care. And this is the entrance to the freezing chamber in which meat and other necessaries are kept fresh to the very end of the journey. There are furlongs of hose, with forcing-engines and all other appliances, to fight the great enemy of sea-going craft. The sturdy crew seem as well trained in their fire-drill as in manning the flotilla of boats that swing from the davits above, prepared for all emergencies.

Admire now the airy kitchens, equipped with every latest invention to save the cooks labour, and their spacious sculleries and pantries; the laundries, store-rooms, cupboards, wine-bins, and all the other domestic paraphernalia of a first-class hotel. But what hotel had ever to provide for so many resident guests? Where is the manager who could serenely contemplate the cutting off of his establishment from all outside support for several consecutive days? No fishmonger, no milkman, no newspaper-boys; neither restaurant, picture-gallery, nor theatre for the ennuyés to resort to! And upon these big liners we find not merely such an assembly as might fill the most capa-

cious hotel, but a population equal to that of many a country town. Three hundred and sixty-five first-class passengers, 160 second-class, and 2352 steerage, with the vessel's own quorum, bring up the temporary inmates of the *Cedric* to nearly 3300 souls.

Let them enter the vessel two by two—the time-honoured fashion in which our youthful fingers filed the animals towards the Ark—they would make a procession about 2 miles long. Or domicile them in houses 4 or 5 storeys high, allowing 10 persons to a house, and 2 feet of frontage to a person, they would fill both sides of a street 5 furlongs ($\frac{5}{8}$-mile) in length. And all these men, women, and children, must be housed and fed, waited upon, and amused, according to their varying requirements, for the space of a week. Calculate the amount of household provision—not simply food of all kinds, liquid and solid, but china, plate, linen, napery—the daily toll of 500 serviettes alone!

All is there, however, awaiting them before they set foot on board, all the conveniences of every-day life in cities demanded by the most exigent traveller. The ever-recurring dainty meals, served by deft-handed waiters; white cloths and glittering glass and silver; palms and ferns and fresh flowers to rest the eye. There is space for games to exercise the athletic. Music and dancing speed the evening hours. While chatting lazily in the cigar-store or refreshment bar we might forget that we are being carried swiftly

across the ocean, save for the breeze which soothes and refreshes our business-jaded faculties. And this upon a steamer designed chiefly for a freight carrier!

In the *Deutschland* and the *Kaiser Wilhelm II.* we recognise the opposite type of vessel,—that built only for conveying mails and passengers at highest speed. The conclusion apparently arrived at by English and American companies, that "excessive speed which means enormous first cost and extravagant running expenses does not pay," is here controverted; for the large subsidies provided by Government enable the German "express" liners to pay their way every trip, and, when full, to make a large profit. The *Kaiser Wilhelm II.* represents the *ne plus ultra* of luxury which twentieth century civilisation has produced, the rush for wealth which almost precludes enjoyment in its possession. The first requisite is hurry—to clench a bargain, to start a new undertaking. So the main engines are the most powerful ever designed, composing a structure 92 feet long, and 43 feet 4 inches in height; the weight of the crank shafts alone being 252,000 lbs. A plant of nineteen boilers provides steam for 4 quadruple-expansion engines, which produce about 40,000 i.h.p., and are intended to drive her through the water at a rate approaching 24 knots. The condensers, through which the steam passes after leaving the last cylinder, are a mass of narrow tubes aggregating 40 miles if laid end to end. The complete driving-shaft is 230 feet long, and the four-bladed bronze propellers—they work at 80 revolu-

tions per minute—are 22 feet, 10 inches in diameter. The boiler-rooms and coal-bunkers (the latter containing 5700 tons) have a total length of 295 feet, and the coal is conveyed to the furnaces along a railway track measuring double that length. Fresh air is conducted to the boiler-rooms through large cowls 69 feet long, and the combustion gases discharge themselves by 4 funnels as in other ships of the same line.[1]

The cast-steel stern-post is of the enormous weight of 253,000 lbs., and the rudder has an elaborate steel protection in case of war. Into this cigar-shaped extension a special steering engine is built, supplemented by one upon the poop-deck, and by a hand-moved tiller should the machinery fail.

The *Kaiser Wilhelm II.* is about the same length as the *Cedric;* but her beam is 3 feet narrower, and her tonnage considerably less, as she is not a cargo steamer. Every modern improvement to ensure safety amid the perils of the seas has been elaborated: such as exceptional thickness of keel-plating; 18 water-tight bulkheads; an extensive system of water and steam pipes, and electric alarm-bells to guard against fire; a fleet of 26 boats; and 27 powerful steam pumps, which can between them discharge 9360 tons of water per hour.

Besides the ship's complement of 600 men, 1888 passengers have to be catered for—773 first-class, 343 second-class, and 770 third-class. There are 4

[1] 237 men devote their services entirely to this department.

separate kitchens, of which the one for the first-class alone is 56 feet long and 30 feet wide, its pantry measures 70 feet by 18 feet, and the sculleries 36 feet by 17 feet; all other appointments in proportion. The storerooms are of vast dimensions, providing a space of 26,000 cubic feet, with refrigerators to keep the contents cool, and a large supply of ice for use.

Space fails us to enumerate the minute particulars of accommodation made for travellers' needs or idiosyncrasies. Two doctors, with a drug store at their disposal, are ready to attend upon the sick. A dark-room awaits the enthusiastic amateur photographer. The two Wiener Cafés combine the open-air enjoyments of the Fatherland with a far-reaching prospect of the glorious sea. A barber's shop lessens the trials of the toilet. And the electric system installed throughout the ship is carried into such practical detail that we may equally light our cigars or curl our hair by electricity!

The children have a saloon to themselves, prettily decorated in red and white, and its walls adorned with paintings representing popular fairy tales. As for the architecture of the suites of assembly rooms, the dining-saloon, drawing-room, smoking-rooms, vestibules and corridors, and the great light-well, whose balconies are supported on graceful colonnades, does it not present the very semblance of a fairy-tale vivified in the mere description? The schemes of æsthetic colouring, varied by pictures and statuettes by eminent artists; the stained glass and

rich brass ornamentations ; the lacquer-work in similitude of birds and flowers ; the silken curtains ; the exquisite mingling of shades in carpets and draperies, all read like a scene from the White Cat's palace of delights.

But we are brought back by a sudden shock to the stern realities of life. Saluting Ludwig Noster's fine portrait of the sovereign whose name the sumptuous vessel bears, we cross the deck reluctantly to leave her. And there confront us the metal beds that enable the peaceful express steamer to develop into a vessel of destruction within a fortnight of the first rumour of coming war.

CHAPTER XVII

FLOATING DOCKS

HOWEVER accurately planned and carefully finished a vessel may be, the time comes when it has to go on to the "sick list." Its ailment may only amount to the need of a fresh coating or two of paint, or the accumulation of barnacles and marine weeds on its bottom may have perceptibly diminished its speed. Or perhaps a storm has handled it roughly, and a plate has started far below the water-line; or it has run foul of a rock, and crushed in a part of its steel walls; and last, but not least, shot and shell may have worked their wicked will upon it.

The repair of a small boat is a simple matter. Just beach it and turn it over. A small ship may be careened, or heeled over till a portion is exposed to the workman. But when huge vessels — liners or ironclads—weighing thousands of tons have to be handled, the question assumes an altogether more serious aspect.

In most of the large ports and dockyards of the world is to be found a contrivance known as a dry-dock, an excavation walled and floored with concrete and masonry, and furnished at one end with stout gates or caissons. The vessel in for repairs is ad-

mitted into the dock, the entrance is closed, and the great pumps on the dock edge set to work to drain off the water. As it recedes, the ship settles slowly down on to the keel-blocks over which she has been centred, and shores are placed on either side to prevent her heeling over. At last the dock is dry, and the carpenters and other mechanics can get to work with scrapers, riveters, and the special tools requisite for the job in hand.

The rapid increase in the dimensions and tonnage of ships has necessitated a corresponding augmentation of the measurements of dry-docks. The *Cedric*, *Oceanic*, and *Kaiser Wilhelm II.* could no more get into the docks of fifty years ago than a man could squeeze himself into the garments of his five-year-old son. Dry-docks 750 feet in length are now quite common, and in several cases this longitude is considerably exceeded. At Liverpool we find a graving (*i.e.* dry) dock 1000 feet long, at Glasgow one of 880 feet, at Tilbury one of 873 feet, at Belfast one of 850 feet. In order to accommodate the largest vessels, the depth of water over the sill of the entrance must be somewhat more than the heaviest draught of these vessels; and to receive them at all times and seasons, the level must be calculated for spring tides, when the tides are at their maximum and minimum heights.

The construction of a dry-dock 800 feet long, 100 feet broad, and 50–60 feet deep is a great undertaking; for these dimensions by no means fully represent the amount of mere excavation. If you dig a deep hole

in your back garden in normally wet weather you will probably find, on reaching a depth of a few feet, that water begins to ooze through. If, therefore, you require a water-tight pit of given dimensions, it will be necessary to clear out an extra foot or so in all directions to allow for a cement or brick lining on five faces. Should your object be a pit at once very deep and dry, your difficulties will be increased by the external pressure of the water, which may be roughly calculated at 1 pound for every 2 feet of depth below the top level of the water-bearing stratum. The thickness of your walls must be increased, and their joints sealed exactly, or you may find that your labour has been in vain.

The dry-dock engineer has to contend with the same difficulties in an aggravated form. His walls are lofty, his floors very spacious. Unless the greatest care is taken, the walls will be bulged in by the earth pressure, and both walls and floor penetrated by the water that must be present in ground near the sea. And, inasmuch as the dock when dry is practically an emptied tank, its total weight or adhesion to the ground beneath must be sufficient to secure it against a tendency to float. The masonry is therefore very massive, and the bottom made in the form of an inverted arch to resist upward pressure and to enable the walls to stand the thrust inwards from the backing. So severe are these thrusts that the Aberdeen Dock—to take an instance—built in 1883–85 of concrete with granite facings, had been so much disturbed and

cracked by 1896, that the owners had to decide between spending £68,000 on its repair, and rebuilding the dock throughout. On the Tyne, also, the bottom of a newly completed dock went wrong, and cost an additional £30,000 before it could handle a ship.

These are, however, exceptional cases, and many docks exist to-day which have done their duty satisfactorily for years, and should last for many to come, since well-laid ashlar work in an ordinary climate will stand practically for ever. The construction of graving-docks is nevertheless a difficult and uncertain matter in some localities, especially in those where the ground is of a sandy or porous nature. Under such conditions the walls and floor must be borne up on long piles reaching down to a more solid substratum. In fact, it is sometimes impossible to build a graving-dock except at a prohibitive cost, and, if the necessity for a means of repairing vessels in a certain locality is unavoidable, recourse must be had to some other means for raising the huge floating forts and ocean leviathans out of the water.

In 1795 one C. Watson took out a patent for a floating dock, a wooden construction of barge-shaped lines, the ends of which could be closed by doors. A ship having been floated in, the doors were closed and the water pumped out, causing dock and vessel to rise above the water-line. A print is extant of such a dock lifting the brig *Mercury* at Rotherhithe about 1800.

Watson's contrivance was very primitive, and cap-

By permission of] [*Messrs. Swan & Hunter, Newcastle.*

The Bermuda Floating Dock.

It is almost fully submerged to allow the *Sans Pareil*, of 10,000 tons displacement, to float in over its pontoons.

[*To face p.* 336.

able of lifting only of what we should consider very small craft. But since his time immense improvements have been made, mainly owing to the substitution of metal for wood. In 1859 Rennie built a large iron floating-dock for use at Cartagena, which is still doing useful work. The floating-docks of to-day are very much more imposing structures than Rennie's, and are of steel, like the ships they are destined to lift.

The floating-dock is in idea a series of pontoons rigidly attached to one another and of great displacement. When full the pontoons naturally sink, and as they are emptied their natural buoyancy serves not only to raise them to the surface again, but also to lift burdens of a weight equal to the difference between their own weight and their displacement.

In section it either resembles the graving-docks, *i.e.* is of a U shape, or the letter L. The latter class is known as an "off-shore" dock, since the upright member must be attached by parallel booms to the shore or some rigid hold in order that it may not heel over when carrying a load on its horizontal pontoon. The U-dock is independent, and may be towed from place to place like an ordinary vessel.

Floating-docks have open ends, and are therefore able to handle vessels longer than themselves. The L docks, being open on one side also, can accommodate ships of greater beam than their pontoons. Modern vessels are very stiff, being practically a powerful form of girder. Their heaviest portion is in the centre, and

although it would put an undue strain on a liner to lift her by bow and stern, leaving her unsupported amidships, to apply the pressure to the central half of her keel only would not be attended with much risk. So we read that the Nicolaieff Dock, 174 feet long over blocks, lifted the *Rossia*, 334 feet long; and the Barrow Dock, 240 feet long, was able to partly raise the *Empress of China* of nearly double its length. The same dock, though only 54 feet in beam, has lifted paddle steamers 68 feet broad.

As regards latitude in dimensions the floating structure has a decided advantage over the graving-dock. Since the latter must have closed ends it is obvious that the length of the vessels it can accommodate is strictly limited. The same is true of their breadth and draught. So that, given two vessels of equal tonnage but different lines, the one might be able to get into dock, and the other be compelled to go elsewhere; whereas the floating-dock would probably be able to handle both with equal ease, or if its buoyancy were not sufficient to lift them clear of the water, it could raise them to a considerable elevation.

Many graving-docks are for reasons of economy so built that vessels can enter them only at high tide: and, as a consequence, leave them only under the same conditions. The advantage of this is, that during low water the level outside the dock is reduced, and with it the hydrostatic pressure. There is less strain on the dock walls, and less leakage. In almost tideless waters, such as those of the Baltic and Mediterranean,

where the level is practically constant, the deep docks must always be subject to heavy pressures; and on the other hand, in localities where the level fluctuates very greatly, as in the St. Lawrence, a dock usable all the year round would have to be of enormous depth. We therefore find the floating-dock largely used in preference to the graving where a constant or very variable level prevails. To render it useful at low water even in shallow roadsteads dredging is indeed necessary, but dredging is inexpensive in comparison with excavation and masonry work on dry land. A sudden rise of level makes no difference to its usefulness.

A further advantage of the floating-dock will easily be recognised by any one who has passed through a river lock. That lock must be completely emptied or completely filled whether the passing craft be a row-boat or a steamer. The smaller the craft the greater will be the amount of water moved. Now, the pumping dry of graving-docks is a costly operation, and would bear heavily on the owners of a small ship in inverse proportion to the size of their vessel. A floating-dock, on the other hand, need be emptied only until the deck of its pontoons is at such a depth that the vessel's keel will clear it as it floats in; and the cost becomes much more directly proportional to the displacement.

The two finest examples of floating-docks are those at Bermuda and Algiers, near New Orleans, built respectively for the British and United States Govern-

ments. Messrs. Standfield & Clark, of Westminster, were responsible for the designs of these mammoth structures.

In 1869 a dock was taken from England to Bermuda, and stationed there for strategical purposes. It is 381 feet long and 84 feet between the side walls, and will lift a ship of 10,000 tons—heavier than the line-of-battle ship of the date of its construction. But so rapidly have the weights and dimensions of large vessels increased, that our warships are now 500 feet in length and of 15,000 tons displacement. The Old Bermuda Dock has therefore become obsolete, and the Admiralty was obliged to replace it by a structure more suited to modern requirements. Borings were made at many points on the island with the intention of deciding a position for a graving-dock, but the geological formation proved to be such as would render the construction of a graving-dock a very expensive matter. The authorities therefore ordered a floating-dock of unequalled dimensions, to cost £250,000, inclusive of its transportation to Bermuda.

The new dock was built by Messrs. C. S. Swan & Hunter, of Wallsend-on-Tyne. It is 545 feet long, and has a clear width between the top of the walls of 100 feet. The walls themselves are 53½ feet high and 435 feet long, and form girders of enormous strength. Three pontoons, secured to the lower portions of the walls by fish-plate joints, lugs, and taper-pins, form the bottom or deck of the dock. The middle pontoon is a rectangle 96 by 300 feet; the end pontoons, each

120 feet long, taper for 49 feet towards their outer extremities to facilitate towing.

The dock, with all its machinery, weighs 6500 tons, and has a lifting power up to deck level of 15,500 tons, though by using the "pound" formed by the bulwark surrounding the pontoon decks additional lifting power up to 17,500 tons can be gained.

When called upon to perform its maximum lift the dock is sunk until the summit of its walls is but 2 feet 6 inches above sea-level. Water is admitted into the three pontoons and the two side walls, and from them removed by eight 16-inch centrifugal pumps at a rate sufficient to lift an ironclad of 15,000 tons in three and a half hours. In order that the dock may not tilt as it rises, the whole is divided into fifty-six divisions, each of which is separately connected with the pumps. By turning off cocks, water can be left in any desired divisions, and the dock forced to incline in any direction for purposes of cleaning and repairs.

It is especially important that a structure of this kind should be self-docking, that is, able to lift any part of itself clear of the water. To expose the bottom of one side the dock is first lowered to a depth of 20 to 21 feet, the water inside the wall compartments being brought to the same level as that of the water outside. The dock is then raised by emptying the pontoons, and when these are exhausted the water is released from the side to be exposed, until the outer corner is 2 feet or more clear.

The pontoons are lifted in turn by withdrawing the

pins of one and allowing it to float while the rest of the dock sinks. The pontoon is then made fast to the walls at its floating level, and the dock emptied, so exposing the whole of the bottom of the raised pontoon. The two end sections can be treated simultaneously, and floated if required on to the central portion, but the latter must be moved only when the other pontoons are in position.

Electric lights and hauling machinery are distributed over the dock. A crane capable of lifting 5 tons runs along each wall from end to end.

The Bermuda Dock was launched at Wallsend in February 1902, the largest floating thing that ever took the water since the time of Noah. It was then towed round to the Medway for a trial with a battleship before being despatched on its 4000-mile voyage to Bermuda, and moored in the deep part of Sea-Reach opposite Port Victoria. The Admiralty selected the *Sanspareil* as the test ship on account of her shape, and the fact that the peculiar distribution of her weight makes her a somewhat difficult vessel to handle. "The battleship was moored just above Sheerness, and about the time of high-water, about 11.30 A.M., she was taken in charge by three dockyard tugs, and brought up to the entrance of the floating dock. Steel-wire hawsers were made fast to the bow, and these being secured to the winches on the dock the hauling-in commenced. There was a strong breeze blowing down the reach at the time, and on the flood this had raised waves of a con-

siderable size for enclosed water, the tide running in this part of the Medway with considerable force. With the turn of the ebb, wind and tide being together, the water was smoother, but still there was considerable motion. This, naturally, did not affect the dock in the slightest degree, as the whole of the pontoon was 28 feet below the water-line, and only the tops of the walls were above the surface. The heavy battleship of over 10,000 tons displacement—she was drawing only 27 feet—had to be hauled in against the tide, which was now running somewhat over 3 knots. Naturally, care had to be taken to keep her keel fairly parallel with the sides of the dock, for, had she got across, her spur would speedily have made a rent in the walls of the dock. With the powerful hauling appliances, however, there was no fear of this, and the vessel was under complete control with the wire hawsers on each side. The ship was centred on the keel blocks, and the upper rows ot shores were fixed in position in something under two hours, and the work of pumping out the dock was commenced at a few minutes past two o'clock. Pumping was continued for fifty minutes, by the end of which time the dock and ship had been raised 13 feet, and it was then necessary to put in another line of shores. This operation occupied a considerable time, and it was late in the evening before the work was concluded, and the ship raised out of the water."[1]

[1] *Engineering*, June 13, 1902.

The trial completed, the dock was towed from Sheerness to Bermuda by two tugs, the *Zwarte Zee* and *Oceaan* of Rotterdam. The only place at which it was necessary to call was the Azores, where the tugs replenished their bunkers. The time occupied was fifty-two days, including the stoppage of three or four days at the Azores; but the progress was sure though slow, and the dock arrived in perfect safety at its destination.

The possible importance of this dock in a naval war in western waters can be judged from the fact, that there is no point within 1000 miles of Bermuda to which a crippled battleship could make for repairs. For some time past the Bermudan authorities have been obliged to send on large vessels to Halifax in Nova Scotia, a voyage which could scarcely be faced by a leaky craft. If strategy demanded, the dock might be taken in tow, and removed to a more favourable position nearer the probable theatre of war.

The second largest, but the most powerful, of floating-docks is to be found at the naval base of Algiers, in the Gulf of Mexico. This dock is 525 feet long, and of the same width as the Bermudan.

Its lifting power up to pontoon deck level is no less than 18,000 tons, and this may be increased to 20,000 tons by utilising the "pound." It is 650 tons lighter than the English dock, and weight for weight more efficient, since every 33 tons has a lifting efficiency of 100 tons, equal to that of 39 tons in

By kind permission of] [*Messrs. Swan & Hunter.*

The "Sans Pareil" in the Bermuda Floating Dock, lifted clear of the Water.

The dock raised her with great ease, since it could deal with vessels displacing 7,500 more tons.

[*To face p.* 344.

the English dock. The general arrangement of machinery is much the same in both docks. The Algiers dock is moored to the shore by two pivoted and hinged booms, which are useful also as gangways.

After its completion by the Maryland Steel Company, Sparrow's Point, Maryland, it was transported to its berth at Algiers, and given a trial with the *Illinois* of about 12,000 tons. As in the case of the *Sanspareil* the docking was conducted without a hitch, though the time occupied was considerably less than that of the Sheerness trial. The contract time for raising the ship clear was three hours, after pumping had once begun. It actually took three hours to get the *Illinois* in position, and two hours less three minutes more to raise the pontoon decks 3 feet above water. The Americans strengthen the bilges of their ironclads with strong bilge docking-keels, forming with the keel proper a level bottom, since the vessel settles on the three bearings simultaneously. No shores are required except those used for roughly centering the vessel, and as a consequence a vessel might be completely docked, if built on the American plan, in the time taken to adjust one constructed on English lines. It remains to be proved whether the presence of bilge keels detracts from a vessel's speed. If not, the American practice appears very preferable, for in war-time despatch in all operations is of the first importance.

Some doubts have been thrown upon the stability of the floating-dock; and indeed it does look at first

sight as though a large tank laden with an ironclad might lose its balance, and share the fate of the *Royal George*. But practical tests banish all such fears; for the Havana dock so burdened would require an effort of 63,502 foot-tons to move it 5 degrees out of the perpendicular, whilst a stress of but 2802 foot-tons would incline the ironclad to the same extent. In other words the laden dock is over twenty times as stable as the ship itself; while it is never likely to have to face such rough weather.

One of the strongest points in favour of this type of dock is its mobility. At its birth it is constructed in the most convenient site possible, viz., the yard of the shipbuilder. On launching it has the whole world open to it. From England one goes to Stettin, another to Havana; a third to Bermuda. On the American side the voyage from Maryland to Algiers is easily made. The only serious mishap in such journeys was that of the Durban Dock, which went aground and became a wreck.

Commercial prosperity not unfrequently deserts one port for another. The floating-dock can follow, while the graving-dock remains—idle. Messrs. Clark & Standfield, in a treatise on the movable type, lay special stress on the value of mobility in war. They see no reason why a floating dock, convoyed by a powerful tug, and fully equipped with stores and tools suitable for rapid repairs, should not follow the movements of a fleet. As they point out, the first sea-fight between fairly matched fleets would leave a

number of wrecks on both sides, and the commander who had the nearest base, and so could "come up to time" again the first, would hold an enormous advantage.

In home waters, too, the dock could play its part. Arsenals are generally placed up some river or creek out of reach of the enemies' guns on the open sea. A ship disabled at the mouth of the Thames, for instance, would have to make for Chatham up the narrow channel of the Medway. Were she to sink in the channel the arsenal would be effectively cut off from any other ships in need of assistance. The floating-dock could be moved down the Thames ready to pick up any of the "lame ducks," and give them "first-aid" in the shape of temporary repairs that would make their hulls tight and in a fit state to navigate the home channels to the fully equipped and protected base hospitals or arsenals. It has been pointed out, with regard to the new Gibraltar docks, that they are open to the fire of the enemy from several points; and the proposition made to add or substitute a floating-dock which could lie in the harbour almost submerged by day, and at night rise to pick up ships needing assistance, or even be towed round to the other side of Europa Point, where it would be protected by the headlands.

In addition to mobility, the floating-dock may claim the following advantages. It can be rapidly constructed, and its price more accurately calculated than in the case of a graving-dock. As an example

of quick erection, we may instance the Havana Dock —of 10,000 tons lifting power—completed in 181 days from the date of laying the first plate. This contrasts favourably with the average time of three or four years required for the construction of a graving-dock of equal capacity.

From the workman's point of view, also the "floater" has its recommendation. Instead of having to work at the bottom of a hole where the light is bad and the air damp, he finds himself on a well-lighted platform swept by breezes—which quickly dry the paint—and free from the discomfort often caused by leakage into a graving-dock.

The latter, if properly made, is more durable than its metal rival. But in these days of rapid advance, types become obsolete so soon that this objection need not be considered. The best testimonial to the general advantages of the floating-dock is that the number of such structures increases from year to year. The more they are used the more they are liked.

CHAPTER XVIII

THE ROMANCE OF PETROLEUM

SECOND to none in commercial importance is the commodity which, in its different forms, lights millions of homes when the sun goes down, sends locomotives spinning along the iron way, makes the motor-car hum over our roads, supplies us with heat for cooking and many industries, lubricates millions of machines, has valuable medicinal properties, and touches our daily life at other points too numerous to mention here.

Petroleum, or rock-oil, has been known to mankind since the dawn of history. Herodotus has celebrated the naphtha springs of Zacynthus, Pliny those of Agrigentum. Many years later Marco Polo quaintly wrote of Baku on the Caspian: "There is a fountain of great abundance, inasmuch as a hundred shiploads might be taken from it at one time. This oil is not good to use with food, but it is good to burn; and is also used to anoint camels that have the mange. People come from vast distances to fetch it, for in all countries there is no other oil like it."

The last sentence, fortunately for mankind, is inaccurate, since petroleum is very widely distributed throughout the world. At present the United States

and the Caspian region are the greatest oil-fields of the world, as regards the quantities extracted for human uses; but huge deposits exist in China, Siberia, Burmah, Asia Minor, Canada, Mexico, Peru, waiting for their turn; and doubtless as the world is better known fresh oil-bearing areas will be discovered.

In Marco Polo's time men, as we have seen, "came vast distances to fetch" petroleum. To-day petroleum comes thousands of miles to every country, town, village of the civilised world! It will be interesting to give some account of the engineering aspects of the system of supply, which circulates many millions of barrels of the useful fluid every year; with reference to the processes for raising and distilling petroleum.

In this connection we will confine our attention to the great oil-areas of America and Russia, where the crude oil occupies innumerable cavities of the earth, ready to give up their treasures the moment the engineer has done his share of the work.

The antecedents of petroleum have been much debated, whether they are of a chemical nature, and therefore connected with distillation that occurred while the Earth was in the making; or are to be considered organic, resulting from the decomposition of vegetable and animal substances in far-off ages. In recent times the latter view has been much taken up by chemists. Further interest attaches to the question whether the supply of mineral oil is a fixed quantity; or whether it is still manufactured by Nature in her

subterranean laboratories. Should the former hypothesis be correct, we must regard the deposits of petroleum as vast storehouses which, when once emptied, will resemble a worked-out bed of coal.

It has, however, been proved that petroleum occurs in geological formations of all periods from the Silurian to the Tertiary, though most abundant in these two, especially the Silurian, with which is closely connected the carboniferous stratum of the Coal Age.

The formation of large petroleum deposits is dependent on three conditions: the presence of a certain class of matter, converted into oil by the process of time; a porous stratum to contain the oil; and an impervious stratum above to prevent evaporation and displacement by water. When the oil is particularly well sealed in by superincumbent matter, the formation of gas subjects it to great pressure, sometimes rising to 800 to 1000 lbs. per square inch, which proves itself, as we shall see, a valuable ally to the engineer.

The petroleum industry may be said to date from the year 1859, when one Colonel Drake sank a well at Titus-ville in Pennsylvania, and "struck ile"—otherwise a fortune—in a "spouter" that emitted a copious supply of the crude material. A year later came the American Civil War; and not till that terrible conflict was over did American enterprise thoroughly rouse itself to exploit petroleum. Then followed scenes which can be paralleled only in the Californian and Australian gold rushes, for the eager-

ness with which men settled on virgin tracts, expended their all in the search for the hidden treasure, and, if successful, gathered about them towns which flourished awhile and then fell into decay as the fields became exhausted. And like the gold-miner, the oil prospector might suddenly stumble on riches, or continue his search, hoping against hope, till beggary stared him in the face.

Every year witnessed the opening of new territory, —Indiana, Kentucky, Missouri, California, Texas, Wyoming, Kansas. By 1900 the output had risen to 57,070,850 barrels, which multiplied by 40 gives the total in gallons. In 1901, the *daily* product was 156,182 barrels. Yet, in 1819, it was considered a mishap to stumble upon petroleum when sinking a brine-well !

Colonel Drake, the pioneer of the industry, drove an iron pipe 36 feet into the rock when boring for oil in the valley of Oil Creek, Pennsylvania. This device, necessary in many cases to hold back the water in overlying strata, is now generally adopted for the American wells.

Having selected a likely spot, the prospector rears a derrick, or lofty wooden frame, 70 feet high, in form a truncated pyramid, resting on a foundation of heavy timbers, enclosing the space in which the well will be sunk. To one side of the derrick is a strong upright post, on which a stout timber, called the "walking beam," works see-saw fashion, actuated by a steam-engine at the one end, and at the other moving a rod

connected with the boring tools. The latter, in American practice, are attached to a rope, which can be paid out as the depth increases, and quickly wound on to special reels when the tools have to be raised for renewal or replacement. The series of drilling apparatus, taken downwards from the walking-beam, is as follows :—

1. A "temper-screw," to which is fastened
2. The rope, 2000 to 3000 feet long.
3. The "sinker-bar," a solid rod of iron, about 20 feet in length.
4. The "jars," a pair of heavy links, allowing about 13 inches of "play," so that the sinker-bar may not strike hard on the boring tools, but yet by its momentum on the up stroke loosen them when the links suddenly tighten.
5. The auger-stem, to which is screwed the
6. Auger or centre bit.

The well-sinker, having his tackle all ready, begins operations by passing the rope over a pulley at the top of the derrick and round one of the drums connected with the winding gear. The engine is then started, and the operator, by alternately slackening and tightening the rope, causes the bars and borer to fall and rise; taking great care that the first length of shaft shall be quite perpendicular.

As soon as a sufficient depth has been reached, and while the auger is at the bottom of the shaft, he threads the rope through the temper-bar on the

free end of the walking-beam. The rope is pulled up until the "jars" are in contact, and then lowered about 4 inches, and made firm in the temper-bar.

The walking-beam has a stroke of 24 inches. The first stroke up does not move the auger from its work until the beam has risen 4 inches, when the jars pluck at the auger-stem and raise it 20 inches. On the down stroke the sinker-bar and top jar fall the full 24 inches, but the auger and stem and lower jar only 20 inches plus the penetration of the fall. An attendant gives the temper-screw a slight turn between every two strokes, so that the auger may continually change its transverse direction, and be able to sink in without closing up the play of the jars. When the screw is run out, the rope is unclamped, the screw wound back, and the adjustment made for a fresh attack; or, if need be, the winding drums are put into action, the tools are drawn up, and the well cleared of sand or rock splinters by a pecular form of "shell" auger.

In this manner a hole is sunk, 8 inches in diameter, to a depth where water is no longer encountered; and lined with a drive-pipe. Through this the boring continues to a point 300 to 400 feet below the surface, where an inner pipe, called the casing-pipe, $5\frac{1}{8}$ inches across, also terminates. Again smaller drills are used, until oil is struck.

A torpedo is then lowered into the well — 1 to 25 gallons of nitro-glycerine — and fired by percussion. The explosion shatters the walls of the bottom of the shaft, and releases the petroleum from

myriads of small cavities, besides splitting the stratum. Soon afterwards the oil spurts from the mouth of the shaft, accompanied by fragments of the canisters that contained the explosives and a shower of pebbles.

The next thing to do is to prepare the well for flowing. A 2-inch pipe, perforated at the bottom, is let down to the oil-level, after being provided with a rubber packing to jam against the sides of the bore. The pressure of the imprisoned gas drives the oil up the pipe like soda-water from a syphon. When its force has expended itself, a pump is inserted into the pipe, and the oil is lifted to the surface.

On the Caspian shore the greatest oil-fields are those of the Apsheron Peninsula, at the east end of the Caucasus. Its 1200 square miles are saturated with petroleum like a sponge soaked in water. The geological foundation of the Caucasus dips under the Caspian and re-appears on the farther side; its course being marked by gas-bubbles which have at times risen with sufficient violence to capsize boats, while the exuded oil is swept by gales into the harbour of Baku, where the careless throwing away of a match may set the Caspian on fire far and wide.

The oil-fields of Balachani, Sabuntchi, Bibi-Eibat, Romany, and Binagadi, are covered thickly with derricks differing in shape little from the American type. The Russian prospector uses both cables and rods to move his drills, but has a preference for rods. As the Baku oil-fields do not hold so much gas under compression as those of Pennsylvania, a "spouter" is

a comparatively rare occurrence, though extremely copious when it does put in an appearance. The majority of Russian oil is therefore brought up by baling; and that the baler—a steel tube 20 to 30 feet long—may have a reasonable diameter, the well must be bored to a considerable size in its lowest depth, usually 800 feet. Water being present in the upper strata the well-sinker has to line his shaft throughout, and, accordingly, begins with an opening 28 to 30 inches across. As the drilling goes on, the tube lining is forced down under great pressure, until it is deemed advisable to contract the bore. Then a tube of smaller diameter is passed through the first and sunk, and as this process is continued the well lining resembles a huge telescope—one that will never be closed. The "eye-end" (*i.e.* lowest tube) may be 8 inches to a foot across.

The greatest calamity that can overtake the engineer is the snapping of his rope or rods. Or perhaps something falls down the well and jams the borer against the steel lining. Six months of hard and expensive labour with a host of different tweezers, probes, cutters, hooks, attached to the end of hundreds of feet of rope may be necessary for the removal of the obstruction. Fishing for the Atlantic Cable was child's-play in comparison with the rescue of a drill from the bottom of a quarter of a mile of tubing.

As soon as the clearing auger begins to bring up a slimy, yellow sand the engineer rejoices, for he knows that he has obtained his reward. The baler, furnished

with a valve at the bottom, is fixed to the rope in place of the drill, and cautiously lowered, time after time, until nothing but pure oil comes up. Then the baling commences in real earnest, without any torpedoing, which would probably do more harm than good by driving great quantities of sand into the bore.

Well-digging is always a speculation. And deep is the joy of the prospector when, by a good stroke of fortune, his borer chances on a cavity where there is imprisoned a large volume of gas. A Russian "spouter" is a fine sight, rising 300 or 400 feet into the air, after very probably demolishing the derrick and its machinery. The proprietor cares nothing for this damage, as the fountain is pouring out in a minute, free of charge, as much petroleum as could be baled in a day. Such a spouter has been known to fling out 100,000 barrels in twenty-four hours; though, of course, the rate of flow rapidly diminishes after the first few days.

The average life of a well is five years. In exceptional cases, however, oil is raised in commercial quantities for thrice that time. In 1899 the huge sum of £2,600,000 was spent on boring alone; and the output of the Apsheron was 52 million barrels. It is noticeable that the depth of new wells increases from year to year.

Owing to the copiousness of the Russian spouter, the engineer must be prepared with proper means for catching a sudden outflow, otherwise he may see a fortune running to waste under his very eyes. The

oil, as fast as it rises, is caught in a sort of compound, whence it is carried by channels to the reservoirs, where the sand is allowed to settle before the liquid is let off through pipes to the refineries at Black Town.

With so much petroleum about, in the earth, on the earth, in the air, in everything (including food), it is not a matter for surprise that disastrous fires should occur, especially in hot weather, when a mere spark is dangerous. Sometimes an open settling reservoir ignites; and then is seen a sight of unsurpassed grandeur, as a huge inky cloud rolls its fat folds of smoke for miles over the landscape. Nothing can be done to quell such a conflagration. But when a spouter catches fire a remedy is at hand. Scrap metal is collected from all quarters, and heaped round the well mouth in the form of a crater. Then steam pipes are applied, and the base of the flame is blown high in the air, separated from its source of supply by a tract of unignited gas. At a favourable moment the metal crater is thrust inward on to the orifice, and the flame immediately dies of starvation.

In its natural state petroleum is of so composite a character, that it must be passed through the refinery, and its various "layers" sorted out by the *still*.

This is in idea a huge closed upright cylinder with a capacity of 10,000 to 40,000 gallons, heated by furnaces beneath, and connected by pipes, passing through cold water, to the receptacles for catching the products of distillation.

The first bodies to pass off from the crude oil are

the very volatile gases, which are condensed back into naphtha and petrol. The still is then cooled, and heated again, this time to a higher temperature, driving off the illuminating oils. Then follow in succession the thick lubricating oils, greases (such as vaseline), and tar.

Russian refiners often use, in the place of a single still heated to different temperatures, a series of smaller stills through which the crude oil slowly passes, giving off in each still the bodies volatilised by the temperature of that particular still, which is not the same as that of the rest of the series. It is claimed for this principle that a great saving of time and fuel is effected, since there is no delay for cooling down or drawing the fires.

American petroleum is much richer in the illuminating oils than is the Russian. And the latter is proportionately more fitted for use as liquid fuel, after the volatile elements, which would be dangerous in a firebox, have been driven off by distillation. The heavy residuum, known as *astakti*, was for years found to be an encumbrance, as the Russian refiners were chiefly interested in producing lamp oil. But Mr. Nobel, a Swede, conceived the idea of utilising the hitherto waste product, by spraying or atomising it with steam, and introducing it in this state into a furnace. As a result, the *astakti* has become of great commercial value; raises practically all the steam-power in South Russia, on both land and river, and is being used in an increasing number of locomotive

and marine fireboxes throughout the world, on account of the ease with which it can be stoked, its comparative cleanliness, and the convenience and economy attending its storage.

The American has copied the Russian example with Texas fuel, which closely resembles the Caspian *astakti*. Texas petroleum is naturally rich in sulphur, which interferes with both storage and combustion. But a method of precipitating the sulphur economically has been discovered, and now Texas fuel is produced transcending the Russian article in its caloric qualities. Large quantities are stored at Thames Haven, whence they are distributed throughout the south of England, replacing the "black diamond" to no small extent.

Dr. Boverton Redwood has calculated that the world's consumption of petroleum represents a continuous flow, at the rate of 3 miles an hour, through a 41-inch pipe! and that the storage of a year's supply would require for its accommodation a tank 929 feet high, long, and broad!

The profitable distribution of such an immense quantity of liquid has taxed the ingenuity of those connected with the traffic. American practice establishes the refineries and reservoirs far from the oil-fields, near the sea, so that, after refining, the oil may be shipped with little delay.

But how to get the petroleum from well to refinery? Oil-fields are generally in rough country, difficult of approach by rail or road. Wheeled transport was

Petroleum "Spouters" on Fire at Baku.

In hot weather when there is a quantity of inflammable gas about, such fires are by no means rare.

[*To face p.* 360.

therefore found expensive, and gradually gave way to a system of transmission by pipe-line from the wells to the seaports.

Individual wells are connected by small pipes to the trunk-lines, which are operated by companies. The proprietor of a well runs off from his own reservoirs, say, 10,000 barrels, for which he obtains a receipt, negotiable like an ordinary cheque. There his part of the transaction ends.

The Standard Oil Company, the largest of its kind, collects the products of the Pennsylvania, West Virginia, and Ohio fields into storage tanks at Olean, N.Y., about 75 miles from Buffalo, with an aggregate capacity of 9,000,000 barrels. From this point starts the great trunk-line, composed of three 6-inch wrought-iron pipes, which run for 400 miles to New York Harbour. There are twelve pumping stations on the line, spaced about 35 miles apart, to pass on the oil at a pressure of about 1000 lbs. to the square inch. In this manner some 1,200,000 gallons are transferred daily from Olean to the Atlantic seaboard, where they are converted by the refineries into burning and lubricating oils, and stored in immense iron and steel tanks until required for shipment to foreign markets. "The main pipe-line is divided into divisions and sections, much like a trunk railway system, and has, similarly, its division superintendents and engineers, section foremen, line gangs and line walkers, telegraph stations, and daily reports. The system works quietly and smoothly, and as the pipes are

buried under ground from 1 to 2 feet, and run through a sparsely settled country, the general public sees or hears but little of the system." [1]

Similar trunk-lines extend from the Ohio fields to Chicago, and from West Virginia and Pennsylvania to Philadelphia and Baltimore.

The Russians are slowly adopting the American plan of transport. Unfortunately for the Baku trade the refineries had been already established on the Caspian, and to transfer the refining industry to the Black Sea would entail great loss to the proprietors of present installations. Also the Black-Sea-Caspian Railway could not spare the revenue derived from the carriage of petroleum on its tank-cars.

The stress of competition has, however, driven the oil-merchants to the pipe-line for part of the distance between Baku and Batoum. Already an 8-inch line has been laid from Batoum to Michaelov, a station on the railway 140 miles from the Black Sea. For the remaining 420 miles the tank-cars are employed; but the shortening of the journey has greatly increased the amount transported daily. In time the line will be completed, and wheeled carriage be entirely obviated.

Prior to 1886 all American oil imported into Great Britain came in barrels. Since that year tank steamers have been introduced generally in the petroleum-carrying trade. These steamers contain from six to ten double compartments, each holding from 85,000 gallons in the case of the smaller steamers to

[1] *Cassier's Magazine.*

250,000 gallons in steamers of the largest size. The tanks are separated from the engines and boilers by a safety well or empty space, which is sometimes filled with water; and the total cargo of oil in bulk carried in this manner is equivalent to 25,000 to 70,000 barrels. In addition to the fifteen steamers which the Anglo-American Oil Company now possesses, it is building what will prove to be, when finished, the largest tank steamer in the world, with an oil capacity of 10,500 tons in bulk, or 73,500 barrels.

On arriving at its journey's end the petroleum is stored into great circular tanks at Purfleet, Birkenhead, Hull, Sunderland, Newcastle, Avonmouth, Plymouth, Belfast, and Dublin. The Purfleet installation covers 30 acres, on which rise many gasometer-shaped receptacles, and mountainous piles of empty barrels. In all important towns are subsidiary storage depôts, and the oil is conveyed to them by means of railway tank waggons, consisting of a cylindrical boiler-plate tank, with a capacity of 3000 gallons, placed horizontally on a flat carriage.

From the 300 provincial depôts the oil is distributed in road-tanks to the shopkeepers, from whom it finds its way to the consumer.

Colonel Drake, drilling in the quiet Pennsylvania valley in 1859, would have needed a more prophetic mind than that of Mother Shipton herself to foresee the benefits he was conferring on the world by laying the foundation of the mightiest trade development history has ever recorded, a development that in less

than forty years has embraced every corner of the globe, and brought light and heat and comfort to hundreds of millions of human beings. It has been truly said that the discovery of gold in California was not so pregnant with the welfare of the human race, since gold concerns the few and light concerns us all. Also that we accept as a matter of course the commoner facts of our existence, and rarely turn our thoughts to the ways and means by which our wants are satisfied. Quite a long chapter has been written on the antecedents of a plum-pudding; the ingredients of which are the outcome of much labour working hand in hand with Nature. And those who know can fashion quite an entertaining story to accompany the lighting of the family lamp, directing the listener's thoughts to the Norwegian forest whence came the wood for the match, to the Carolina cotton-fields that contributed the material for the wick, to the Pennsylvanian and Russian oil-fields, where the illuminant was won from the darkness of the nether earth; to the Bohemian glassworks that fashioned the transparent tube which draws the flame into the bright radiance of perfect combustion.

Mention has been made of the natural gas which aids the oil miner by driving the petroleum deposits to the surface. In some parts of America, notably Indiana and Ohio, it occurs in such volumes as to become a valuable commodity that can be turned to good account as a lighting and heating agent.

An adit is bored to the subterranean gas cavities,

and the issuing gas is collected from the various wells; if so, they may be called into central reservoirs for propulsion through trunk pipe-lines to distant centres of industry. One such line connects the Indiana wells, some sixty in number, with Chicago, 140 miles away. Compressors, which can be worked at a maximum pressure of 2000 lbs. per square inch, force the gas into the mains under a stress of 300 lbs. The mains are two 8-inch wrought-iron pipes, laid under ground, and connected at intervals by a "by-pass," which enables the contents of either to be switched into the other channel. At the Indiana boundary line the pressure is "stepped down" to 40 lbs., and the diameter of the pipes increased to 10 inches; from which it issues on reaching the town at a 1-lb. pressure into an extensive system of distributing mains ramifying throughout the streets.

Pittsburg is in like manner supplied from Ohio with a natural power which, even when conveyed for many miles to the consumer, still costs less than the same power produced on the spot. The utility of the gas may be estimated from the consumption, which in Chicago rises to several million cubic feet daily; while in Pittsburg it has to a great extent ousted coal, though some of the most extensive coal-fields of America are in the neighbourhood of the town. In course of time the natural-gas supplies will be exhausted, and Pittsburgians will turn again to King Coal, if that monarch has not been already dethroned by the electricity from Niagara

CHAPTER XIX

ARTESIAN WELLS

In our third chapter we treated of the artificial river, the aqueduct, confined to its course by walls of rock, cement, and metal.

The artificial spring, being of at least equal importance as a source of water-supply, is also worthy of notice; and the reader will probably be interested to learn some facts concerning the thousands of holes with which the engineer has riddled the upper crusts of the earth in his search for the pure fluid that is so necessary an adjunct to our daily life.

The type of well that most often strikes our attention is a hole several feet in diameter, lined with brick and cement, into which water collects from the surface. Sometimes the "dug-out" is of considerable depth, and as we peer cautiously over the brink we behold our reflections far below in what appear to be the very abysses of the earth.

Such a well is often picturesque and useful. But its day has passed—at anyrate in thickly-peopled districts. For the chemist, with his test-tubes and microscope, and delicate scales, has but too often a doleful tale to tell of the contents of such receptacles. Even if their main supply comes from below, a

certain amount of leakage from the surface is inevitable, and the "merry microbe" soon finds its way in, to the condemnation of the whole supply.

Sometimes we may see, in newly developed building properties, or even in the open country, a small gang of men busy round a steel tripod, raising and lifting a vertical bar, on which their attention is centred. If our curiosity is sufficiently aroused to cause a closer inspection, we observe that the bar is slowly, but surely, eating its way downwards, and that other bars have to be screwed on to it from time to time; these also disappearing in turn.

The driving of an Artesian well is in progress. The workmen have good reason to suppose that beneath their feet exists a natural reservoir of good water. It may be 100 feet down, or perhaps 1000, and their duty is to hunt for it until found, when it may gush from the bore-hole in a fountain, after the manner of a petroleum "spouter," or merely rise to a level from which pumps will bring it to the surface.

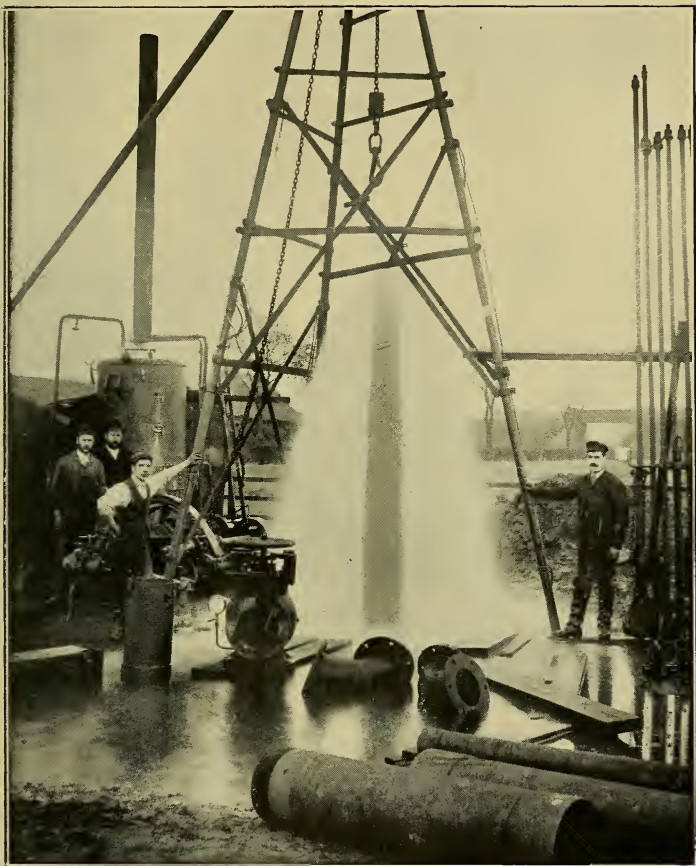
The word Artesian is connected with the French province of Artois, where this method of well-boring was first practised in Europe, though known to the Chinese for centuries previously.

It may appear, at first sight, a mystery that in many places a well can be sunk for, say, 50 feet, without yielding any sign of water, and yet deliver a copious amount if the boring be continued for another 500 feet. The riddle is, however, easily solved.

Imagine a huge natural basin, many miles across, lined all round with clay or some other impermeable stratum; on the top of that a porous layer of chalk, sandstone, or sand; on the top of that again more clay. Perhaps in the course of centuries the basin is filled up level by deposits of various natures, and finally a town built over it. We may suppose that the area of the basin is not blessed with a heavy rainfall; but that its rim on one or more sides emerges from the earth near a range of hills, or even mountains, which cause the condensation of the clouds passing over them. The water running down the slopes encounters the basin-rim, sinks into it, and finds its way between the water-tight strata to the lowest point unoccupied. In course of time the basin lining has sucked in all that it can hold, and overflows at the rim. But the water may become contaminated as it settles into the contents of the basin, and so lose the purity of the hills.

The well engineer, to whom the geology of a district is known, is not disturbed by the apparent scarcity of good water, since he has only to sink a small shaft into the lowest part of the lining to obtain command of its entire contents. If the basin is but partly filled in, so that the centre lies lower than the sides, as soon as his drills touch the water-bearing stratum a fountain shows itself, in obedience to the natural law that water must seek its own level.

London lies over such a basin. Hundreds of Artesian wells have been driven down to the lining,



From a photo lent by] [*Messrs. C. Isler & Co.*

Bourn Artesian Well, near Spalding, Lincolnshire.

This well yields over 5,000,000 gallons a day, and may therefore be considered the most copious of its kind in Europe. It is 134 feet deep, and 13 inches in diameter. On the right will be seen some of the rods used in the boring of the shaft.

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which through them yields many million gallons a day to the Metropolis.

The reader will now be able to understand the "spouting-bores" of the most arid tracts of Australia and North Africa. The water that spirts from them in sufficient quantity to keep alive millions of sheep and cattle comes from hills that may be hundreds of miles away, through the natural aqueduct formed by two impervious strata enclosing one that has the qualities of a sponge.

The depth at which a sealed water-bearing stratum exists varies enormously in different localities. Thus the Bourn Well, Lincolnshire (of which an illustration is given), descended but 134 feet before it tapped a source that poured over 5,000,000 gallons a day from its orifice! In the London area it is necessary to bore from 300 to 500 feet, according to position. And London is well off in this respect as compared with Paris, where the chalk strata lie six times as far below the surface. Among the most famous of Parisian wells is that at Grenelle, which was seven years in the drilling, a fifteen months' delay being caused by the breakage of the boring rods at a depth of over 1250 feet. On reaching 1500 feet without finding water, the engineers would have abandoned the attempt but for the representations of Arago, the famous French astronomer and natural philosopher, who urged them to persevere, with the result that at 1798 feet the drills suddenly sank into a cavity from which warm water spouted at the rate of 36,000 gallons an hour.

In 1855 another well, 1923 feet deep, was driven down to the same stratum, with a bottom diameter of 28 inches. So great was the pressure that the outflow rose 54 feet into the air, to the extent of over $5\frac{1}{2}$ million gallons a day.

Even these were completely eclipsed in profundity by a well near Berlin, which attained a depth of 4194 feet, piercing a salt deposit 3900 feet thick.

Examples of such wells could be multiplied, as the progress of engineering science has made their execution more easy from year to year.[1]

In practice the sinking of Artesian bores much resembles the driving of a petroleum well, described in a previous chapter. But a water shaft, being intended for a permanency, and having as its object the promotion of health, must be sunk with especial care, and its joints rendered absolutely impervious to impure leakage. By means of Artesian bored-tube wells, any depth and all sorts of strata can be penetrated. There are various methods of boring; one by connecting lengths of iron rods together, to which the various tools are attached, and working the whole up and down until the encountered matter has been pounded into a sludge, which is removed, after the

[1] In Queensland alone over 800 Artesian and sub-Artesian (*i.e.* non-flowing) wells have been sunk. The bores have an average depth of 1188 feet, but about sixty range between 3000 and 5045 feet. The yield from one bore is 6,000,000 gallons a day, from another 4,500,000 gallons, while sixty more contribute over 1,500,000 gallons. The water from many of the bores has eaten out a course for more than 40 miles, but is now directed by proper channels to the irrigation of thousands of acres of sugar and other tropical and sub-tropical products.

lifting of the rods, by a shell-auger or sludge-pump. This is called the percussion system.

A second is practically that of the American oil seeker. The rods are replaced by a rope, and the weight is concentrated in the drills and their attachments.

A third method of percussion employs hollow instead of solid rods for moving the auger. Water is forced through the rods down to the extremity of the perforator, and on its return to the surface brings with it all the débris. Whenever this principle can be used it proves most expeditious and economical, as the tools need not be removed from the hole for clearing purposes.

The fourth is a true drilling method, since the cutter remains in contact with its work all the time. It is effected by means of a ring of diamonds attached to the end of a circular hollow borer. The diamond drill is a most useful weapon in the hands of the prospector as well as the water engineer, because it enables him to rescue from the depths the solid core that the cutter has gradually absorbed into the hollow rods on its downward path. By inspecting the cores it is easy to see almost at a glance the nature of the stratum being worked; whereas under the percussion systems the "slurry" comes up in the form of an unrecognisable sand or sludge.

So great is the hardness of the diamond, that it can cut thousands of feet through the hardest rock without appreciable damage to itself. Hence the well-sinker

employs it wherever possible, putting it aside as soon as a soft or friable stratum is met, and returning to his percussion tools. The last two methods can conveniently be used conjointly, as the same set of hollow rods will serve for the two different types of auger. The smallest diamond drills, worked by hand, take cores about an inch in diameter for holes up to 400 feet in depth, while the largest stock size produces a core 16 inches across (weighing upwards of 3 tons), and can be successfully operated at a depth of as much as a mile.[1]

The engineer lines the bore as it sinks with steel tubes, connected by almost flush joints of the same metal, until he reaches the chalk. Sometimes, to prevent any possibility of leakage past the tube, he first inserts an outer lining which descends to below the permeable surface strata. The annular space between the two tubes (both of which reach to the surface) is filled in with concrete, and made absolutely watertight. On occasions, however, as soon as the inner tube has been firmly imbedded, the outer is removed for use in another place.

With regard to the quantity of water obtainable by means of Artesian bored-tube wells, it is unlimited, as the yield can be increased by connecting a series of

[1] In Upper Silesia a bore 6571 feet was sunk in search of the coal measures. This bore began with a 12-inch diameter, which decreased by stages to $2\frac{3}{4}$ inches. At 6560 feet the weight of tubular boring rods was $13\frac{1}{2}$ tons; 11 feet lower, 4500 feet of rods broke off and fell to the bottom, whence the engineers were unable to rescue them. This depth is considered to be about the limit of present-day apparatus.

tubes together to a main, and attaching the pumps direct to it.

In some cases the process of well-boring may appear tedious, especially when deep layers of clay, and quicksand, overlying the water-bearing seam, necessitate the lining of the hole as each foot is drilled, and also the elimination of objectionable springs; but even under these conditions it is very much more expeditious than digging a 5- or 6-foot shaft on the old plan. By keeping the lining tubes of the same diameter from top to bottom the drills can be driven down with wonderful perpendicularity, which favours the subsequent introduction of apparatus for pumping.

When once the water-seam is struck the action of pumping tends to increase the supply, by clearing the fissures and crevices of the rocks, which have become partly clogged through the continuous working of the tools during the operation. But should it happen that the supply shows signs of decreasing, other artificial means of creating a freer water-way can be resorted to, first among which stands blasting with torpedoes of nitro-glycerine. The cartridge is made of a tin case into which the explosive is pressed and hermetically sealed by the detonator placed on the top. The cartridge is lowered by means of an independent wire or chain, and suspended on the spot where it is to be fired. The firing takes place from the surface by electricity, after every one has stood clear of the bore-hole,

from which débris is sometimes shot with great force.

In many cases the results are marvellous. Thus at some cement works near Rochester, a single gelatine cartridge, weighing 18 lbs., was exploded at 307 feet from the surface in the lower greensand formation, which at this spot is composed of rocks and compact sands, with the result that 20,000 gallons per hour are now obtained, whereas no supply existed previously.

If the water flows up spontaneously the engineer is spared further trouble; but it more generally happens, especially in districts where a large number of bore-holes have lowered the "head" of water in the chalk or sand from which supplies are drawn, that it becomes necessary to employ artificial methods of raising the water to the surface. Every one is acquainted with the common lift-pump, and this is often used in Artesian wells. But a much more effective and economical device is the "air-lift."

This system is at work in America and on the Continent, and a number of permanent installations have been laid down in England. The general arrangement is simplicity itself. A powerful steam-engine compresses air into a receptacle, from which it is conducted through a small pipe down the bore-hole to some distance below the surface of the water. It then turns upwards a few inches, ending in a nozzle that enters a second and larger pipe rising to the surface, this pipe being open at the bottom. The

air rushing up the larger pipe at a pressure of 100 lbs. to the square inch, or more, in proportion to the height of the lift, raises the well water with it, in a manner similar to that of a steam injector forcing water into a boiler against a high steam tension.

The simplicity of the whole system and its advantages are obvious. It is evident that sandy particles raised with the water will not damage a plant free from valves or moving parts. Once fixed, the air and water pipes need no attention whatever, as the motive machinery is all above ground. Pumping plant of the ordinary character cannot be duplicated, for the reason that one bore-hole will not hold two sets of deep well pumps; but with the compressed-air system emergencies can be provided for by the addition of a second compressor and reservoir.

For limited depths and supplies, and in strata which, though perhaps hard and compact, are not composed of actual rock, the "driven tube" forms a most useful well, capable of being sunk at great speed to a sufficient distance to avoid risk of surface contamination.

The well consists of a hollow wrought-iron tube about 1¼ to 6 inches in diameter, composed of any number of 3- or 10-foot lengths, according to the depth required. The most important part of the tube is the point, a hollow spike 2½ feet long, perforated all round.

The spot for driving having been chosen, a truly vertical hole is first made in the ground with a crowbar, and the point and first length of tubing inserted. A driving-cap, connected rigidly to the bottom of a

vertical steel rod, is then slipped over the top of the pipe to receive the blows of the heavy cylindrical weight which moves up and down outside the rod just mentioned, hoisted by ropes working through pulleys in a tripod connected to the top end of the rod.

This form of well-sinking is generally similar to ordinary pile-driving, except in so far as the pile is a single continuous body, while the tube is constantly added to, length by length, as the point penetrates deeper into the stratum.

When water shows itself a pump is rigged to the pipe, and suction applied to raise the fluid to the surface. Then it is suddenly allowed to sink back into the tube, forcing obstructive matter from the clogged apertures of the point. This operation of "tilting," or causing the water to be played in and out of the perforations, is most important, and if improperly or insufficiently done may result in the choking of the well.

The well-borer has an armoury full of tools as varied and weird-looking as those of a dentist; for like the latter he must be prepared for all sorts of operations that may seldom occur, yet are unavoidable when they do. His drills assume all shapes. Some are V-ended, others square-ended; some of T-shaped section, others straight-sided, for polishing up the bore; or spiral, to attack gravel and sand; or fitted with springs, so that they may enlarge the bore below the pipe, and yet be easily removed. Here is a weapon that resembles a large corkscrew for recovering a rod

from the depths of a well; and another, called a "crow's-foot," that serves the same purpose; and yet a third, styled a "bell-box," that is let down on to broken rods, passes over a joint, and grips it fast when drawn upwards.

Without these multifarious devices many a well would have to be abandoned after it has been sunk for hundreds of feet, and with it a great quantity of pounds, shillings, and pence.

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THE END

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